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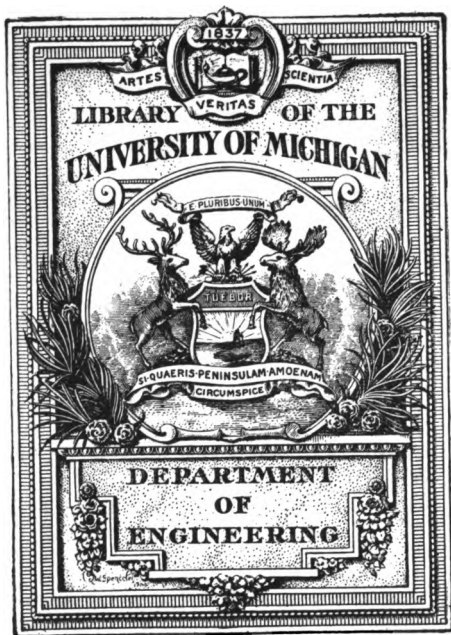
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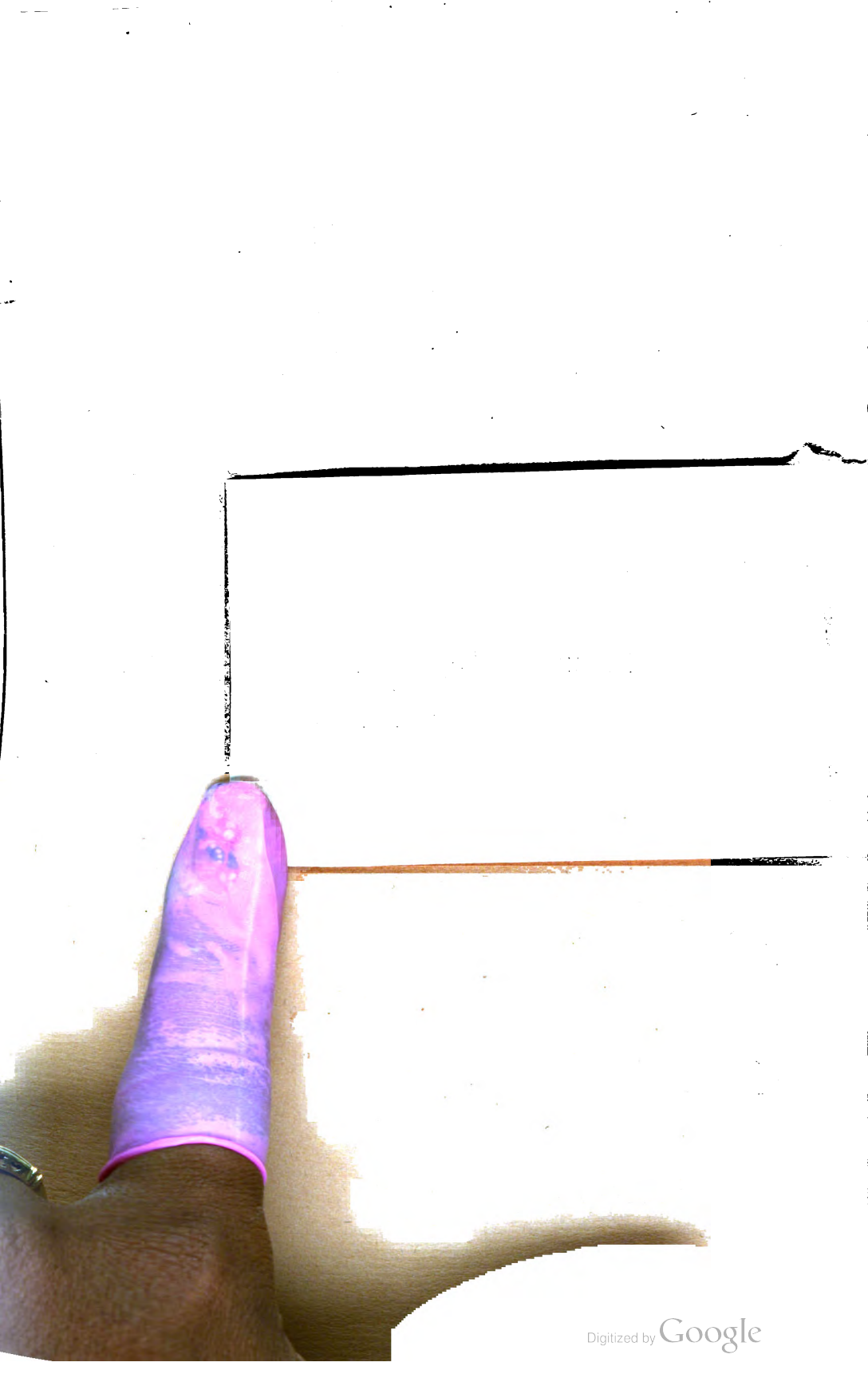
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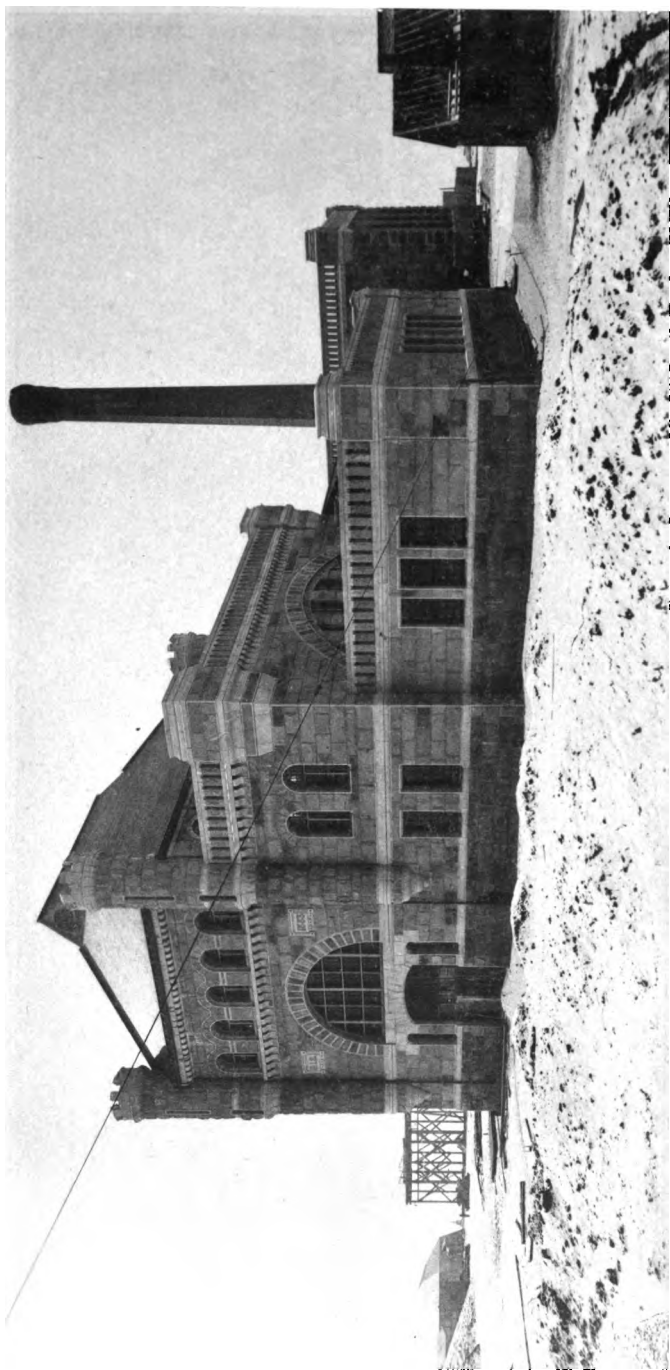
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With Compliments of

William Jackson,

City Engineer.





Main Drainage Pumping Station. Front View.

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MAIN DRAINAGE WORKS

OF THE

CITY OF BOSTON, E. J. d. y. t.
(MASSACHUSETTS, U.S.A.)

BY

ELIOT C. CLARKE

PRINCIPAL ASSISTANT ENGINEER, IN CHARGE



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PREFACE.

THIS brief description of the Main Drainage Works, of Boston, aims to record, for the benefit of engineers, an account of the engineering problems involved and the methods of construction adopted. It also aims to give to the tax-payers and general public a descriptive account of why the large appropriation for "An Improved System of Sewerage" was needed, and how it has been spent. By attempting to accomplish both of these purposes it fulfils neither of them adequately; since one class of readers will find it too technical, and the other too deficient in detail. It has been prepared amid pressing engagements, and to save time the writer has not hesitated to borrow freely from previous reports, by himself and others. Traces of such compilation will, doubtless, be noticed by the discerning. It is hoped that a fair idea of the works can be obtained from the illustrations; and that the description, even by its defects, may encourage other engineers to publish, as they too seldom do, accounts of works with which they have been connected.

E. C. C.

Boston, April, 1885.

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MAIN DRAINAGE WORKS.

CHAPTER I.

EARLY HISTORY OF SEWERAGE AT BOSTON.

THE conditions which necessitated a change in the system of sewage disposal at Boston, and the problems to be solved in making that change, can be better understood after a brief consideration of the early history of sewerage at that city and the manner in which the sewers were originally built.

Boston was first settled in 1630. When the first sewer was built cannot now be determined, but it was earlier than the year 1700, for already, in 1701, the population being about 8,000, a nuisance had been created by frequent digging up of streets to lay new sewers and to repair those previously built; and in town meeting, September 22, 1701, it was ordered, "That no person shall henceforth dig up the Ground in any of the Streets, Lanes or High-ways in this Town, for the laying or repairing any Drain, without the leave or approbation of two or more of the Selectmen."

The way in which sewers were built at this time was, apparently, this. When some energetic householder on any street decided that a sewer was needed there, he persuaded such of his neighbors as he could to join him in building a street drain. Having obtained permission to open the street or perhaps neglected this preliminary, they built such a structure as they thought necessary, on the shortest line to tide-water. The expense was divided between them, and they owned the drain absolutely. Should any new-comer, or any neighbor, who had at first declined to assist in the undertaking, subsequently desire to make use of the drain, he was made to pay for the privilege

what the proprietors saw fit to charge. When a drain needed repairing all persons using it were expected to pay their share of the cost.

As might have been expected, under such a system, great difficulty was experienced in distributing fairly the expenses and in collecting the sums due; so that it became of sufficient importance to engage the attention of the Legislature, and in 1709 an act was passed regulating these matters. It is entitled, "An Act—Passed by the Great and General Court or Assembly of Her Majesty's¹ Province of the Massachusetts-Bay. For regulating of Drains and Common Shores."² For preventing of Inconveniences and Damgages by frequent breaking up of High-Wayes . . . and of Differences arising among Partners in such Drains or common Shores about their Proportion of the Charge for making and repairing the same."

The act recites that no person may presume to break up the ground in any highway within any town for laying, repairing or amending any common shore, without the approbation of the selectmen, on pain of forfeiting 20 shillings to the use of the poor of said town; that all such structures, for the draining of cellars, shall be "substantially done with brick or stock;"³ that it shall be lawful for any inhabitant of any town to lay a common shore or main drain, for the benefit of themselves and others who shall think fit to join therein, and every person who shall afterwards enter his or her particular drain into such main drain, or by any more remote means receives benefit thereby, for the drainage of their cellars or lands, shall be obliged to pay unto the owner or owners a proportionate part of the charge of making or repairing the same, or of that part of it below where their particular drain enters. In case of dispute the selectmen decided how much each person should pay, and there was an appeal from their decision to the courts.

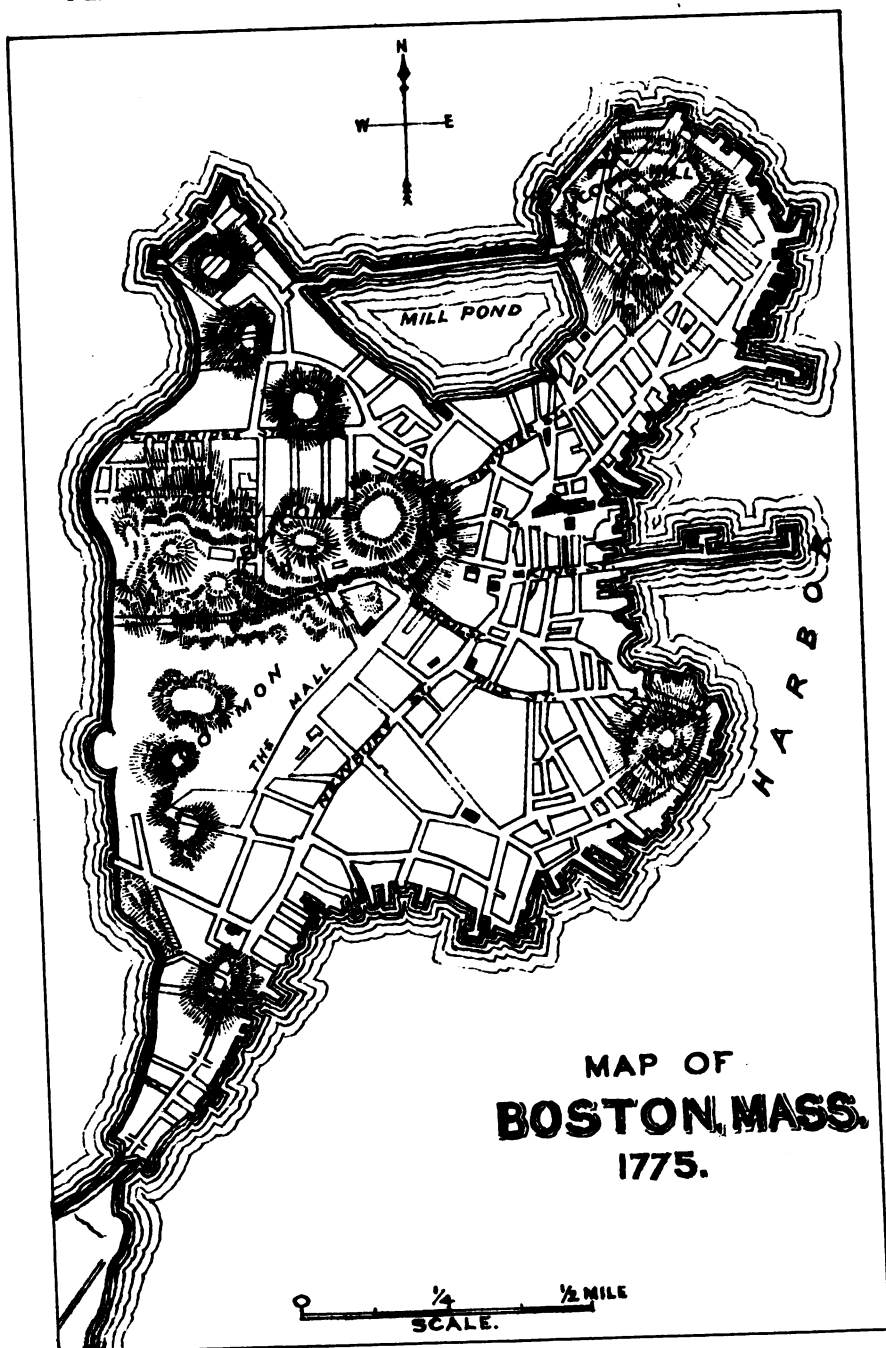
For one hundred and fifteen years the sewers in Boston were built, repaired, and owned by private individuals under authority of this act.

It may be doubted if most of them were "substantially done with brick or stock," and there certainly was much difficulty

¹ Anne.

² Sewers.

³ Stone.



about payments ; so that in 1763 the act of 1709 was amended, the amendment reciting that "Whereas it frequently happens that the main drains and common shores decay or fill up . . . and no particular provision is made by said act to compell such persons as dwell below that part where said common shores are repaired, and have not sustained damage, to pay their proportionable share thereof, as shall be adjudged by the selectmen, which has already occasioned many disputes and controversies," therefore it was decreed that in future all persons benefited should pay for repairs.

No further change was made till 1796, and then only to provide that persons who did not pay within ten days of notification should pay double, and that the sewers, besides being of brick or stone, might be built of such other material (probably wood) as should be approved by the selectmen.

Under this act the greater part of Boston was sewered by private enterprise. The object for which the sewers were built was, as indicated "for the draining of cellars and lands." The contents of privy-vaults, of which every house had one, and even the leakage from them, were excluded ; but they received the waste from pumps, and kitchen sinks, and also rain-water from roofs and yards.

That much refuse got into them is proved by their frequently being filled up, and as they had a very insufficient supply of water they were evidently sewers of deposit. That they served their purpose at all is due to the fact that the old town drained by them, as shown in Plate I., consisted of hills with good slopes on all sides to the water. Of this early method of building sewers Josiah Quincy, then Mayor, said, in 1824 : "No system could be more inconvenient to the public, or embarrassing to private persons. The streets were opened with little care, the drains built according to the opinion of private interest or economy, and constant and interminable vexatious occasions of dispute occurred between the owners of the drain and those who entered it, as to the degree of benefit and proportion of contribution."

In 1823 Boston obtained a city charter, and one of the first acts of the city government was to assume control of all exist-

ing sewers and of the building and care of new ones. The new sewers were built under the old legislative acts, and the whole expense, as before, was charged to the estates benefited, being divided with reference to their assessed valuation. A small, variable portion of the cost was, however, generally assumed by the city, in consideration of its use of the sewers for removing surplus rain-water from the public streets.

The city ordinances regulating sewers required that, when practicable, they should be of sufficient size to be entered for cleaning. Some supervision was exercised over connecting house-drains, and, if thought necessary, a strainer could be placed on each. Fecal matters were rigidly excluded until 1833, when it was ordered that, while there must be no such connection between privy-vaults and drains as would pass solids, the Mayor and Aldermen, at their discretion, might permit such a passage or connection as would admit fluids to the drain. This action was perhaps due to an advent of cholera during the previous year. To assist in flushing out deposits, it was provided, in 1834, that any person might discharge rain-water from his roof into the sewers, without any charge for a permit. The same year control of the sewers and sewer-assessments was given to the City Marshal. He was especially to devote himself to the collection of assessments, new and old, which were largely unpaid. The other duties of the marshal probably prevented him from devoting sufficient energy to the accomplishment of this task; for it appears that, while there had been expended by the city, for building sewers, from 1823 to 1837, the sum of \$121,109.52, there had been collected of this sum but \$26,431.31.

That there might be some one to give his whole time to the financial and administrative duties connected with the sewerage system, a "Superintendent of Sewers and Drains" was appointed in July, 1837. He was empowered to assess the whole cost of any new sewer upon the real estate, including buildings benefited by it. In 1838 the city decided to assume one-quarter of the gross cost; and in 1840, in obedience to a decision by the Supreme Court, it was ordered that the three-quarters of the cost of sewers which was to be paid by the

abutters, should be assessed with reference to the value of the land only, without taking into consideration the value of buildings or other improvements, and such has been the practice up to the present time.

It is estimated that there are at the present time (1885) about 226 miles of sewers in Boston. In 1873 there were about 125 miles, and in 1869 about 100 miles. There are at present supposed to be more than 100,000 water-closets in use in the city; in 1857 there were 6,500.

CHAPTER II.

CHARACTER AND DEFECTS OF THE OLD SEWERAGE SYSTEM.

SUCH changes have taken place in the contours of the city, through operations for reclaiming and filling tidal areas bordering the old limits, that, from being a site easy to sewer, Boston became one presenting many obstacles to the construction of an efficient sewerage system.

This will be understood from an examination of the plan of the city proper, Plate V. On this plan the shaded portion represents the original area of the city, and very nearly its limits in 1823. The unshaded portion of the plan, indicating present limits, consists entirely of reclaimed land filled to level planes little above mean high water, the streets traversing such districts being seldom more than seven feet above that elevation. A large proportion of the house basements and cellars in these regions are lower than high water, and many of them are but from five to seven feet above low-water mark, the mean rise and fall of the tide being ten feet. This lowness of land surface and of house cellars necessitates the placing of house-drains and sewers at still lower elevations. Most house-drains are under the cellar floors, and fall in reaching the street sewers; the latter must be still lower, and in their turn fall towards their outlets, which were rarely much, if at all, above low water.

Moreover, as filling progressed on the borders of the city, it became necessary to extend the old sewers whose outlets would have been cut off. The old outlets being generally at a low elevation, even where the sewers themselves were sufficiently high, the extensions had to be built still lower, and when of considerable length could have but little fall towards the new mouths.

As a consequence, the contents of the sewers were dammed back by the tide during the greater part of each twelve hours.

To prevent the salt water flowing into them many of them were provided with tide-gates, which closed as the sea rose, and excluded it. These tide-gates also shut in the sewage, which accumulated behind them along the whole length of the sewer, as in a cesspool; and, there being no current, deposits occurred. The sewers were, in general, inadequately ventilated, and the rise of sewage in them compressed the foul air which they contained and tended to force it into the house connections. To afford storage room for the accumulated sewage, many of the sewers were built very much larger than would otherwise have been necessary, or than was conducive to a proper flow of the sewage; and, as there would have been little advantage in curved invert where there was to be no current, flat-bottomed and rectangular shapes were frequently adopted.

Although at about the time of low water the tide-gates opened and the sewage escaped, the latter almost immediately met the incoming tide, and was brought back by it, to form deposits upon the flats and shores about the city. Of the large amount of sewage which flowed into Stony Brook and the Back Bay, and especially that which went into South Bay, between Boston proper and South Boston, hardly any was carried away from the vicinity of a dense population.

The position of the principal sewer outlets and of the areas on which the sewage which caused most offence used to accumulate, is indicated on Plate V. From these places foul-smelling gases and vapors emanated, which were diffused to a greater or less distance, according to the state of the temperature or of the atmosphere. Under certain conditions of the atmosphere, especially on summer evenings, a well-defined sewage odor would extend over the whole South and West Ends of the city proper.

This evil was thus described by the City Board of Health in one of their annual reports : —

Complaints of bad odors have been made more frequently during the past year than ever before.

They have come from nearly all parts of the city, but especially and seriously from the South and West Ends.

Large territories have been at once, and frequently, enveloped in an atmosphere of stench so strong as to arouse the sleeping, terrify the weak, and nauseate and exasperate everybody.

It has been noticed more in the evening and by night than during the day; although there is no time in the whole day when it may not come.

It visits the rich and the poor alike. It fills the sick-chamber and the office. Distance seems to lend but little protection. It travels in a belt half-way across the city, and at that distance seems to have lost none of its potency, and, although its source is miles away, you feel sure it is directly at your feet.

The sewers and sewage flats in and about the city furnish nine-tenths of all the stenches complained of.

They are much worse each succeeding year; they will be much worse next year than this.

The accumulation of sewage upon the flats and about the city has been, and is, rapidly increasing, until there is not probably a foot of mud in the river, in the basins, in the docks, or elsewhere in close proximity to the city, that is not fouled with sewage.

Various palliative measures were adopted. The Back Bay, into which the waters of Stony Brook, and with them most of the sewage of Roxbury and Jamaica Plain, used to empty, was lately partly filled with gravel, forming the present Back-Bay Park. The brook was carried in a covered channel to Charles River, which somewhat lessened the nuisance caused by it, or at least transferred it to another locality. Owing to complaints from the physicians of the City Hospital and other residents in that neighborhood the city purchased and filled the upper portion of Old Roxbury Canal at the head of South Bay. The sewers emptying into it were extended, and the position of the nuisance caused by them was thus altered by a few hundred feet. In general terms it may be said that none of the old sewer outlets were in unobjectionable locations.

There are no plans in detail of the sewers of Boston. Many of the older ones have no man-holes. In some streets several sewers exist side by side. Occasionally a sewer is found built directly above an older one. Probably one-half of the larger main sewers are wholly or partly built of wood and have flat bottoms. An unwise provision was inserted in the charters of some of the private corporations organized for the purpose of reclaiming and filling areas of flats, by which it was stipulated

PLATE II.



Fig. 1



Fig. 2



Fig. 3



Fig. 4

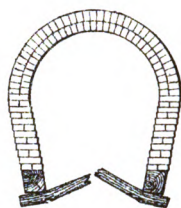


Fig. 9



Fig. 10

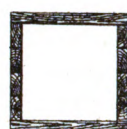


Fig. 11

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Fig. 5



Fig. 6



Fig. 7



Fig. 8

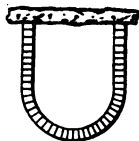


Fig. 12

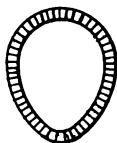


Fig. 13

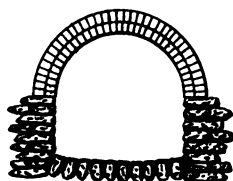


Fig. 14

IRON TYPES OF ON CITY SEWERS.

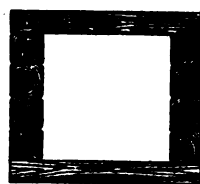
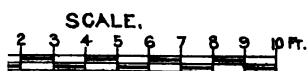


Fig. 16

USE DRAINS.



26



27



28



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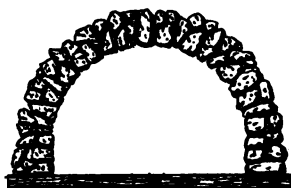


Fig. 19

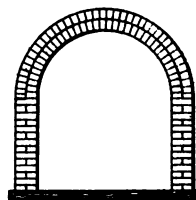


Fig. 20

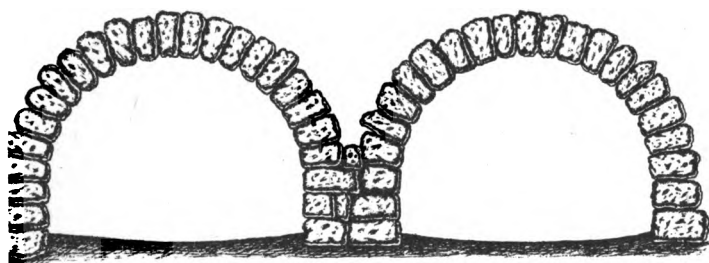


Fig. 22.

that the corporations should themselves extend all sewers whose discharge would be obstructed by the filling. Such extensions were made without system, by building flat-bottomed wooden scow sewers, which were laid upon the soft surface of the flats before the filling was done. Cross-sections of various common forms of existing city sewers are shown on Plate II., Figs. 1 to 22. Fig. 22 shows Stony-Brook culvert, which constitutes the lower mile of Stony Brook, and is that part of it which is covered and used as a sewer.

One fact which increased the danger arising from the damming up of the sewers, and the consequent compression of their gaseous contents, was that the house-drains connecting with these sewers were ill adapted to resisting this pressure. Most of them were built of brick or of wood, before the rise of modern ideas in regard to sanitary drainage; and, as they were usually leaky, the gases forced into them found ready egress into the houses. Figs. 23 to 29 on Plate II. show common forms of these house-drains.

The drains differ greatly in size. Of 113 which were observed while building the intercepting sewers in 1878, —

11 were about 4 inches in diameter.

4	"	5	"	"	
21	"	6	"	"	
5	"	7	"	"	
27	"	8	"	"	
8	"	9	"	"	
11	"	10	"	"	
26	"	12	"	"	or more.

113

Of these 113 drains, 9 were level and 14 pitched the wrong way; 45 had flat bottoms and 68 curved ones; 38 were wholly or partly choked with sludge, and 75 were reasonably clean. At about the same time examinations made with peppermint, by the City Board of Health, of 351 house-drains in various sections of the city, showed that 193 of them, or 55 per cent., were defective in regard to tightness.

CHAPTER III.

MOVEMENTS FOR REFORM—COMMISSION OF 1875.

FOR the ten years preceding 1875 the average annual death-rate of Boston was about 25 in 1,000. On April 14, 1870, the Consulting Physicians of the city addressed to the authorities a remonstrance as to the then existing sanitary condition of the city, in which they declared the urgent necessity of a better system of sewerage, stating that it would be a work of time, of great cost, and requiring the highest engineering skill.

At about the same time, and in each of their Annual Reports thereafter, the State Board of Health referred to the matter, saying that the question of drainage for Boston and its immediate surroundings was of an importance which there was no danger of overstating.

Of such great importance was the matter considered by the State Legislature that, in the special session of 1872, an act was passed authorizing the appointment of a commission, to be paid by the City of Boston, to investigate and report upon a comprehensive plan for a thorough system of drainage for the metropolitan district. This was not accepted by Boston, on the ground that the expense should be shared by the neighboring cities and towns, and no commission was appointed.

In a communication to the City Council (Dec. 28, 1874), upon the necessity of improved sewerage, the City Board of Health pointed out clearly the evils of the existing system, and strongly urged that a radical change should be made. March 1, 1875, an order passed the City Council authorizing the Mayor to appoint a commission, "consisting of two civil engineers of experience and one competent person skilled in the subject of sanitary science, to report upon the present sewerage of the city . . . and to present a plan for outlets and main lines of sewers, for the future wants of the city." The Mayor thereupon appointed as members of the commission Messrs. E.

S. Chesbrough, C.E., Moses Lane, C.E., and Charles F. Folsom, M.D., and in December of the same year their report was submitted.

As was to be expected from the professional attainments and reputation of these gentlemen, the report contained a comprehensive and exhaustive statement of the defects in the existing system of sewerage, and of the causes which had produced such a condition of affairs, and finally recommended for adoption a well-considered plan for remedying present defects and for providing for future needs.

The commission stated, as essential conditions of efficient sewerage: first, that the sewage should start from the houses, and flow in a continuous current until it reached its destination, either in deep water or upon the land; and, second, that the sewers should be ventilated so that the atmosphere in them should attain the highest possible degree of purity. To quote from the report:—

The point which *must* be attended to, if we would get increased comforts and luxuries in our houses, without doing so at cost of health and life, is to get our refuse out of the way, far beyond any possibility of harm before it becomes dangerous from putrefaction. In the heat of summer this time should not exceed twelve hours. We fail to do this now in three ways:—

First. We cannot get our refuse always from our house-drains to our sewers, because the latter may not only be full themselves at high tide, but they may even force the sewage up our drains into our houses.

Second. We do not empty our sewers promptly, because the tide or tide-gates prevent it. In such case the sewage being stagnant, a precipitate falls to the bottom, which the slow and gradual emptying of the sewers, as the tide falls, does not produce scour enough to remove. This deposit remains with little change in some places for many months.¹

Third. With our refuse, which is of an especially foul character, once at the outlets of the sewers, it is again delayed, there to decompose and contaminate the air.

As a result of this failure to carry out the cardinal rule of sewerage, we are obliged to neglect the second rule, which is nearly as important, namely, ventilation of the sewers; for the gases are often so foul that we cannot allow them to escape without causing a nuisance; and we compromise the matter by closing all the vents that we can, with the certainty of poisoning the air of our houses.

¹ The catch-basins, too, in the course of the sewers, serve only to aggravate this evil, and should be filled as early as is practicable.

In the opinion of the commission there are only two ways open to us. The first, raising more than one-half of the superficial area of the city proper (excluding suburbs) is entirely out of the question, from the enormous outlay of money which would be required, — more than four times as much as would be needed for the plan which we propose, and which consists in intercepting sewers and pumping.

There are in use now in various parts of the world three methods of disposing of the sewage of large cities, where the water-carriage system is in use: —

First. Precipitation of the solid parts, with a view to utilizing them as manure, and to purifying the streams.

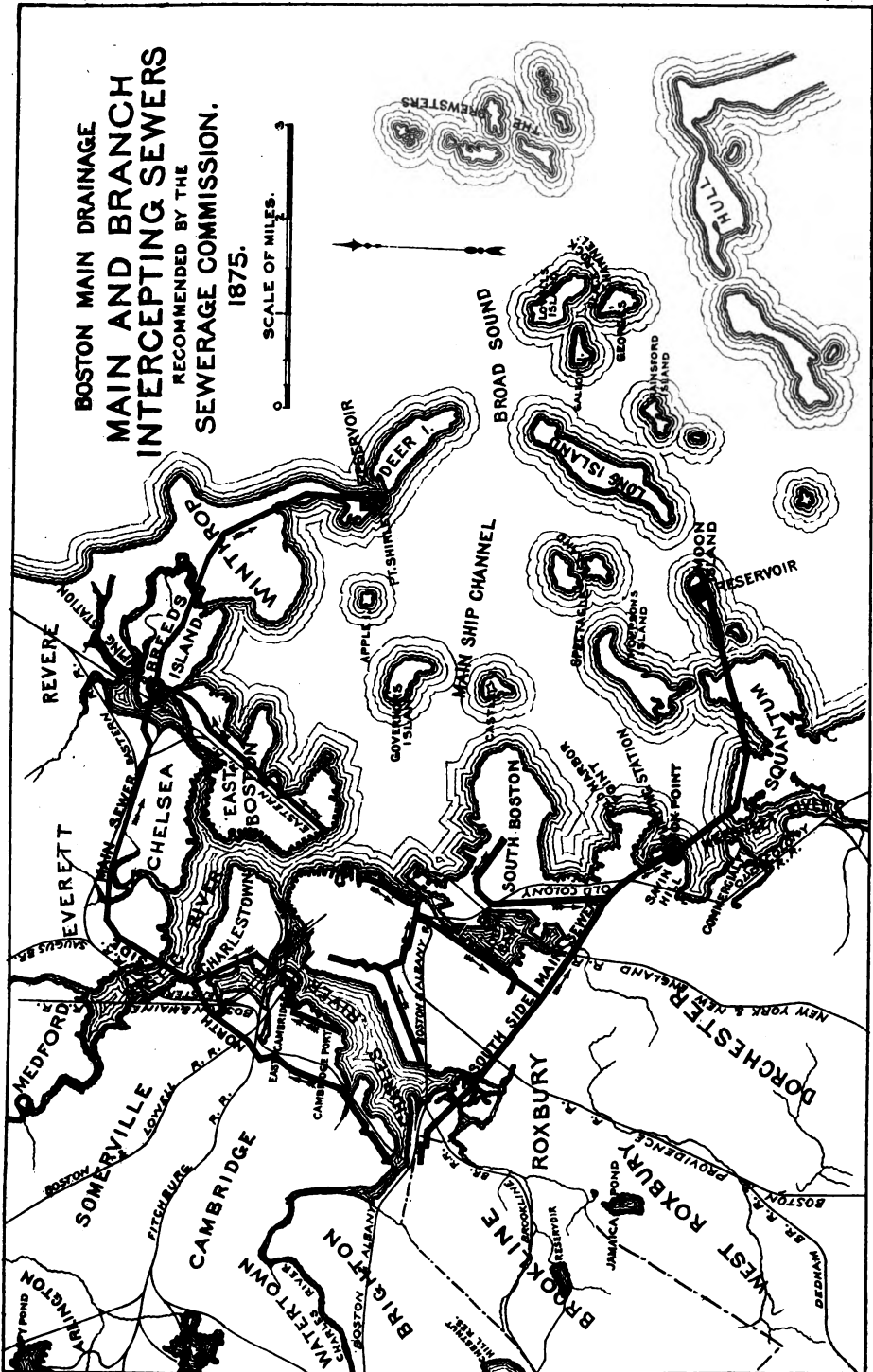
Second. Irrigation.

Neither of these processes has proved remunerative, and the former only *clarifies* the sewage *without purifying* it; but if the time comes, when, by the advance in our knowledge of agricultural chemistry, sewage can be profitably used as a fertilizer, or if it should now be deemed best to utilize it, in spite of a pecuniary loss, it is thought that the point to which we propose carrying it will be as suitable as any which can be found near enough to the city, and at the same time far enough away from it.

The third way is that adopted the world over by large cities near deep water, and consists in carrying the sewage out so far that its point of discharge will be remote from dwellings, and beyond the possibility of doing harm. It is the plan which your Commission recommend for Boston.

On Plate III. is reproduced a portion of the plan accompanying the report of the commission. The plan shows the routes of the main, intercepting, and outfall sewers recommended, and the proposed locations of the pumping-stations, reservoirs, and outlets. It will be seen that two main drainage systems were proposed, one for each side of the Charles River; that on the south side having its outlet at Moon Island and that on the north side discharging at Shirley Gut.

The former system was designed to collect and carry off the sewage from all of Boston south of Charles River and from Brookline; the latter was to drain the Charlestown and East Boston districts, and also the neighboring cities of Cambridge, Somerville, and Chelsea. The two systems were identical in their general features. These were: intercepting sewers along the margins of the city to receive the flow from the already existing sewers; main sewers into which the former were to empty and by which the sewage was to be conducted to pumping-stations; pumping machinery to raise the sewage about 35



feet; outfall sewers leading from the pumping-stations to reservoirs near the points of discharge at the sea-coast, from which reservoirs the sewage, accumulated during the latter part of ebb and the whole of flood tide, was to be let out into the harbor during the first two hours of ebb-tide.

The cost of the proposed main drainage works, as estimated by the commission in its report, was : —

For the territory south of Charles River	.	.	\$3,746,500
“ north “	.	.	2,804,564
Total	.	.	<u>\$6,551,064</u>

The commissioners' recommendation met with very general acceptance. But, as was to be expected, a certain amount of opposition to it was encountered.

One remonstrance against the adoption of the proposed plan, which was presented to the City Council by a number of estimable citizens, may be of sufficient interest to cite, because it is a type of the kind of objections which are often urged against plans for municipal improvement, however carefully considered by the most competent experts : —

The undersigned respectfully remonstrate against the adoption of the system of sewerage proposed in Report No. 3 of this year. We believe if carried into execution it will prove not only ineffectual, but destructive to the health and prosperity of the city. . . . Of late years the cost of many, if not most, of the public works has greatly exceeded the estimates; in some instances, it is said, two or three hundred per cent.

Should this new system exceed the estimates *to a like extent*, the amount would be augmented to between fifteen and twenty millions of dollars. . .

But we do not believe it (flushing) will, or even can, be made to perform that end in an effective or satisfactory manner; because we understand, by the report, that the inclinations of the sewers will afford a flow at a minimum rate of only two miles an hour, so that it will be almost impossible to prevent the glutinous slime and putrefactions from constantly gathering and adhering more or less to the sides and bottoms of the sewers and drains, and as constantly exhaling the deadly gases on every side. . . . It will likewise be borne in mind that the thick mass of liquid corruption within the sewers and drains must be drawn along to their uphill or final ascent of thirty feet and over, and kept in motion and delivered at the distant outlets on the bay, by means of enormous pumps and machinery worked by steam-engines, . . . for a stoppage in the oper-

ations of such an extensive system for only a day or two, along the low lands and other parts of the city, would almost inevitably result in serious maladies and other evil consequences. . . . Will not the exhalation and odor (from the storage reservoirs) blown by every changing wind here and there along the wharves, upon the shipping and back upon the land, create a nuisance so offensive and unhealthful as to become intolerable? No provision seems to be devised to prevent such emanations or their baleful consequences. In these noisome reservoirs the contents must ever be exposed to the sun, the storms, and the inclemency of the weather.

In the severity of winter they must become as frozen as the water in the bay or along the shores; and as often as they are converted into ice there must be an entire stoppage of the works. . . . Such reservoirs and outlets might be reduced to ruins in any future day of hostilities — either foreign or domestic — should such hostilities ever occur, the effect of which ruins would be the fatalities of the plague. . . .

There is now but a single system before the authorities, although there are not less than five different systems in Europe alone. . . . It is hereby requested that the same be postponed, and that a reward be offered for the best plan for sewerage relief . . . and that such plans be referred to a commission of citizens . . . with power to give the reward for the best plan.

Other remonstrants thought that city sewage had a great manurial value, and should be so utilized as to be a source of revenue; still others considered the proposed scheme extravagant, and advised temporary palliative measures.

What prevented these remonstrances from having much weight, was that while criticising the proposed scheme, they either suggested no alternative plan, or else failed to show that the method which they themselves recommended would remedy the existing evils.

As a compromise the City Council inclined to adopt the recommendations of the commission in so far as they referred to the territory South of Charles River, which included those portions of the city which suffered most from ineffective sewerage. Application was made to the Legislature for authority to construct works in general accordance with the recommendations of the Commissioners, and an act, approved April 11, 1876, entitled "An Act to empower the City of Boston to lay and maintain a main sewer discharging at Moon Island in Boston Harbor, and for other purposes," was passed.

The subject had been referred by the City Council to a Joint

Special Committee on Improved Sewerage, and in June, 1876, this committee reported, recommending the adoption of the system devised by the commission, and that surveys and estimates be made for the work, and also that the feasibility of an outlet at Castle Island be considered.

By an order approved July 17, 1876, the sum of \$40,000 was appropriated for the purpose of making surveys and of procuring estimates for an improved system of sewerage for the City of Boston, on a line from Tremont Street to Moon Island, and also on a line from said street to deep water east of Castle Island.

A few days later the City Engineer, Mr. Joseph P. Davis, appointed the writer principal assistant, in immediate charge of the survey and investigations, which were at once begun.

CHAPTER IV.

PRELIMINARY INVESTIGATIONS.

By a liberal interpretation of the order in compliance with which the survey was carried on, it was assumed that any information was desired which might be of use in designing main drainage works, in general accordance with the plan recommended by the commission.

As the location of the outlet would affect materially the whole scheme its consideration received the earliest attention. It was necessary that the discharge should be into favorable currents, and also near a practicable site for a reservoir which could be reached by the outfall sewer from the city. A party for hydrographic work was organized, consisting of one assistant engineer, one additional observer, two sailing-masters, and two boatmen. Their outfit included a small yacht and two tenders.

A projection of the harbor was first made, and the triangulation points given by U.S. Coast Survey were plotted upon it, together with others obtained by ourselves from these, by means of the plane table; the shore line being taken from a chart belonging to the Harbor Commissioners. A sufficient number of prominent points having been determined in this way, it was easy at any time to locate the position of a float by the sextant. At night, when other objects could not be seen, the harbor lights furnished points for observation.

Some difficulty was experienced in deciding upon the best form of float. That first adopted consisted of four radiating arms, with canvas wings projecting downward from them (Plate IV., Fig. 4). Upon calm days this form indicated very fairly the surface velocity; but was too easily influenced by winds and waves to be used in windy weather, as it then invariably grounded on a lee shore.

A "surface and sub-surface" can-float (Plate IV., Fig. 5) was

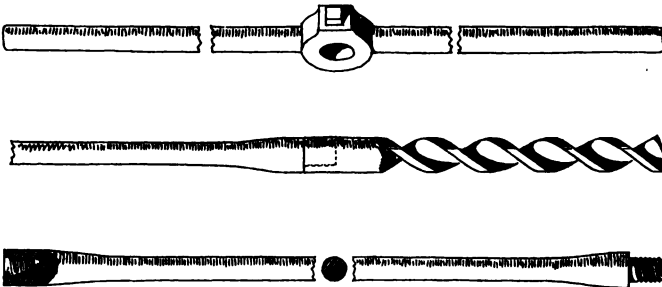


FIG. 1.

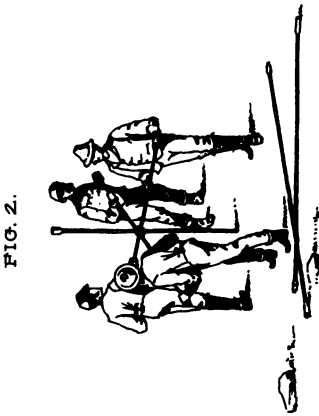


FIG. 2.

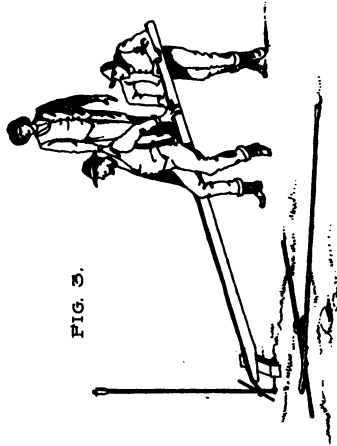


FIG. 3.

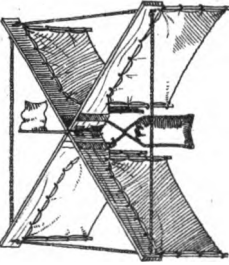


FIG. 4.

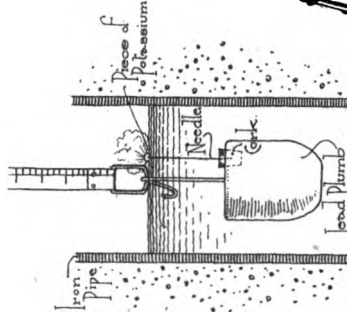


FIG. 7.

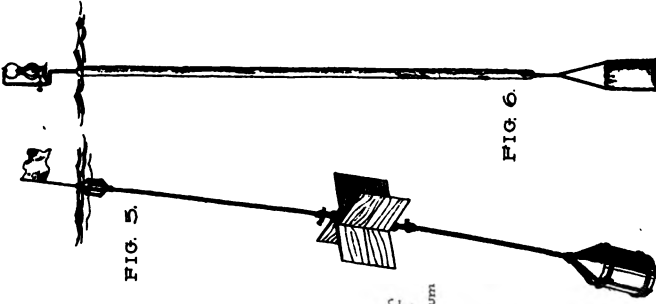


FIG. 5.

FIG. 6.

used somewhat, and gave better results ; but an ordinary pole-float (Plate IV., Fig. 6), about 14 feet long and 4 inches in diameter, was finally found to be the most satisfactory, indicating the mean current, which often differed both in direction and velocity from the surface current. This float supported a flag, or lantern, and, when there was danger of its grounding, a shorter one was substituted for it.

In all, about 50 "free-float" experiments were made upon the currents in the vicinity of Moon, Castle, Thompson's, and Spectacle Islands. The trips varied in duration from 6 hours, or one ebb-tide, to 52 hours. Angles to determine the position of the float were taken each half-hour, and were recorded together with the direction and force of the wind and other data. During observations a man was stationed at a tide-gauge, and all velocities were reduced to a mean rise and fall of ten feet. The results obtained from the float experiments, stated briefly, were as follows :—

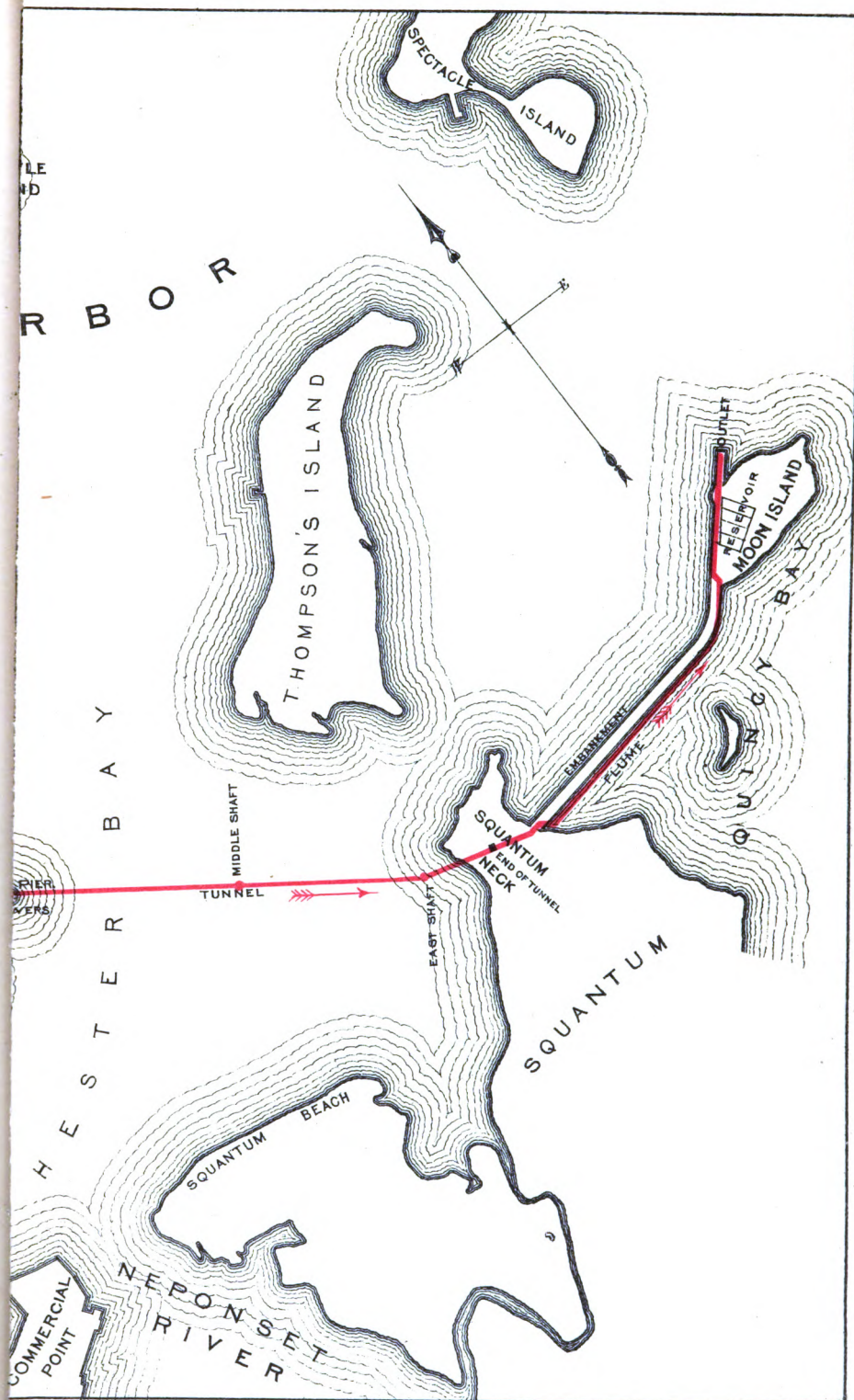
Favorable ebb currents were found to pass both Moon and Castle Islands. That passing Spectacle Island was sufficient in strength, but unsuitable, owing to its direction and some other characteristics ; while that skirting Thompson's Island was altogether unfavorable. Floats leaving the vicinity of Moon Island with the early ebb would travel seawards with an average velocity of .74 miles an hour, passing between Rainsford and Long Islands, through Black Rock Channel, and at the turn of tide would reach a position between the Brewsters and George's Island about four miles from the point of starting. This course is, for its whole extent, outside of the inner harbor. Floats from Castle Island followed Main Ship Channel and Broad Sound, and travelled about as far as those from Moon Island. Returning with the flood-tide the floats would travel about two miles towards the city, and with the succeeding ebb would once more move seaward, not again to enter the harbor.

Sewage, being fresh water, remains for a while at least upon the top of the denser sea-water, and is more affected by surface currents than by deeper ones. An attempt, more interesting than practically instructive, was made to ascertain to what extent sewage put into Boston Harbor would be diffused within

a few days. Fifty bottles were put into the water at Moon Island, each containing a postal card, which the finder was requested to mail, stating when and where it was found. Ten of these bottles were picked up within the next three weeks. One of them was found at Marshfield, about 25 miles south of its starting-point; another at Salem, about the same distance north; a third, 30 miles south-east of Cape Ann, and the remaining seven outside of Cape Cod, near Provincetown, Wellfleet, and Chatham, from 50 to 80 miles distant.

Castle Island would have been much more easily accessible from the city than Moon Island, but its selection involved several serious disadvantages. It belongs to the United States, and is the site of Fort Independence. Although this old fort is of little practical value, there were no reasonable grounds for hope that the government would permit a storage reservoir to be located on the island. It would have been necessary to place that structure on the main land in South Boston. The area available for the purpose would have been restricted on account of its great cost. Even if the works could have been so constructed as to be wholly inoffensive, the natural prejudice in the community against the proximity of sewage would have caused great opposition to the building of a reservoir so near to a densely populated district. Moon Island, on the contrary, afforded an excellent site for a reservoir. The neighboring country is sparsely settled, and there is no dwelling within a mile of the works. The outlet, therefore, was finally located at this point.

The next problems considered were the selection of a route for the outfall sewer between the city and Moon Island and the location of the pumping-station. As any route would necessarily cross a portion of the harbor near the mouth of Neponset River, it was thought best to explore the nature of the ground underlying the harbor in that vicinity. To this end a number of artesian borings were made from a scow fitted for the purpose. Five-inch or smaller gas-pipe was driven to the required depth, varying from 20 to 100 feet, and the earth excavated from within them. In all, 139 such borings were made. Those on the line selected by the commissioners, between Fox



Point and Squantum Beach, showed deep beds of mud underlaid by sand and gravel; so that any method of crossing at that point would have been difficult and expensive. Moreover Fox Point was thought to be too near to the valuable residence property of Savin Hill to make it a suitable place for a pumping-station. Borings at the mouth of the river opposite Commercial Point also found deep beds of mud, but the crossing being much shorter, it would have been comparatively easy to have constructed a stable siphon on that line. Commercial Point itself was a fairly good site for a pumping-station, but would have been somewhat difficult of access from the city. Ground suitable for tunnelling was discovered between Old Harbor Point and Squantum Neck. This was the most direct line from the city to Moon Island, and comparative estimates showed it to be also the cheapest line. Its chief merit, however, which caused it to be selected, was that it permitted the use of Old Harbor Point as a site for the pumping-station. This point comprises over 100 acres of marsh land, valued by the city assessors at only \$200 an acre. It is itself destitute of habitations, and sufficiently remote from any to afford assurance that operations carried on there will not be a source of offence.

Before adopting the tunnel line a plan was considered by which the sewage, instead of being raised at Old Harbor Point, was to flow thence by gravitation to a pumping-station at Moon Island, on a nearly direct line between the two points. The sewer was to be built above ground and sunk into a trench dug to an even grade in the bottom of the harbor. To determine the feasibility of this plan borings were made to test the nature of the ground on the proposed line. The character of the ground developed by these borings was not considered very favorable, and a decision of the Harbor Commissioners requiring the sewer to be placed lower than was considered practicable caused the proposed plan to be abandoned.

Having decided to locate the pumping-station at Old Harbor Point the routes of the main and intercepting sewers were next selected. The peculiar geological formation of the region about Boston, causing frequent elevation of the bed-rock, not

always shown by surface indications, and the sometimes unsuspected presence of deep beds of marsh mud, rendered it necessary to test carefully the nature of the ground through which it was proposed to build the sewers, since its character would form such an important element in their cost and stability. The slowness and expense of artesian methods of boring precluded their use. Light auger-rods were therefore constructed, and it was found that by them the character of the ground could be ascertained with approximate accuracy and with little expense or delay. These tools, and the manner of using them, are shown on Plate IV., Figs. 1 to 3. Including work done before and after the beginning of construction, more than 30,000 lineal feet of borings were thus made, at an average cost of about 25 cents per foot.

There was no trustworthy information extant concerning the position and condition of the city sewers which were to be intercepted. Careful surveys were therefore made, of about 50 miles in extent, of such sewers as were in the vicinity of the proposed intercepting sewers. Plans and profiles of these were made, with cross-sections and such details of construction as could be ascertained.

Nearly all buildings in the Back-Bay and South-End districts of the city are supported on piles. By city ordinance the tops of the piles are not to be higher than Grade 5, or mid-tide level; in fact many of them are a foot or two higher. Fears were expressed that the intercepting system (by doing away with the semi-daily damming up by the tide of the contents of the sewers) might lower considerably the soil-water in such regions, and, by reducing it below the tops of the piles cause them to decay and endanger the stability of the buildings supported by them.

To see if such danger was to be apprehended, it was decided to produce in one of the Back-Bay sewers the precise condition which would exist if the new system was constructed, and to notice the effect upon the soil-water. To this end a steam pump was put into the Berkeley-Street sewer near the outlet and by continual pumping (except at low tide) the sewage was kept but a few inches deep, as it would be if discharging

into an intercepting sewer. Previously 20 pipes had been driven below the surface of soil-water; some within a few feet of the sewers, others a few hundred feet away, and still others several blocks distant. The height of the soil-water standing in each pipe was measured twice each day during the continuance of the pumping.

The method of making these measurements was ingenious, and perhaps novel. The elevation of the top of each pipe was known, and the distance from the top to the surface of water was taken with a steel tape. To the bottom of the tape was attached a lead weight, with a needle fixed in its top so adjusted that the point of the needle was just opposite to the end of the tape. A small bit of metallic potassium was put on the point of the needle. The instant this touched the water it ignited explosively, and the flash and sound could be easily distinguished from above. A sketch of the apparatus is shown by Fig. 7, Plate IV.

It was found that the surface of the soil-water was nearly level over the whole Back-Bay district, averaging 7.7 feet above mean low water, and its height, while slightly affected by local contours of the surface, was independent of the sewers in its vicinity. For instance, the water in the vicinity of the Dartmouth-Street sewer was at the same level as that near the Berkeley-Street sewer, although the latter sewer is two feet lower than the former. Also it was found that the soil-water rose and fell, responding quickly to any rain or melting of snow (the extreme rise due to four inches of surface-water being one foot), and that the variation was nearly uniform over the entire district.

Finally it appeared that the pumping, which continued 53 days, affected but slightly, and that only within 100 feet of the sewer, the soil-water in the vicinity of Berkeley Street. At the close of the experiment, the sewer resuming its former conditions, the soil-water in its immediate vicinity rose from an inch to an inch and one-half, and thereafter fluctuated in unison with the water in other localities.

The experiment was thought to show that no dangerous low-

ering of the ground-water need be apprehended in consequence of the adoption of an intercepting system.

The following was the general basis of calculations for amounts of sewage and sizes of sewers. It was necessary to assume some limit to the territory which should be tributary to the intercepting system. A natural limit in this case seemed to be afforded by the Charles and Neponset Rivers, which, with Mother Brook connecting them, include an area of about 58 square miles. Of this area about 46 square miles is high land, 40 or more feet above low water, and, as suggested by the commissioners, drainage from districts above Grade 40 could, if necessary, be intercepted by a "high-level" intercepting sewer and could flow by gravitation to the reservoir at Moon Island. There remain 12 square miles below Grade 40 which must forever drain into the "low-level" system. As, however, it will be long before the high-level sewer is built, and in the mean time sewers from areas above Grade 40 must connect with the low-level system, for purposes of calculation, it was assumed that 20 square miles would be tributary to the proposed system.

The prospective population was estimated at an average of $62\frac{1}{2}$ persons to each acre, or 800,000 in all. This estimate of $62\frac{1}{2}$ persons to the acre was used in calculations affecting the main sewer; but in proportioning branch intercepting sewers greater densities of population were assumed, to provide for possible movements of population. The amount of sewage per individual was estimated at 75 gallons, or 10 cubic feet, in each 24 hours. The maximum flow of sewage per second was estimated at one and one-half times the average flow due to 10 cubic feet per day.

On this basis the maximum flow of sewage-proper to be provided for would be $\frac{800,000 \times 10}{24 \times 60 \times 60} \times 1.5 = 138.88$ cubic feet per second.

This amount was nearly doubled by adding to it 100 cubic feet per second as a provision for rain-water. This would represent a little less than one-fourth inch of rainfall in 24 hours, per acre of tributary area; but it was intended, in practice, to

admit little, if any, rain from regions where the cellars were not subject to flooding, and reserve the full capacity of the sewers and pumps to relieve certain low districts where the cellars are generally much below high tide, and were often partly filled with water in time of rain.

For purposes of calculation, therefore, the prospective maximum flow per second in the main sewer was assumed to be $138.88 + 100 = 238.88$ cubic feet per second. The inclination of the sewer was 1 in 2,500, and it was designed (as were all of the sewers) to flow about half full with its calculated maximum amount of sewage. Although this rule required that the sewers should be larger than they would be if designed to flow full, it was adopted because it gave about three feet less depth of excavation for the whole sewer system, saved three feet lift in pumping, provided storage-room for large additional amounts of sewage due to intermission of pumping or to rain, and afforded more head-room to workmen entering the sewers.

In designing the smaller intercepting sewers the method employed was somewhat as follows: the districts drained by the several city sewers were ascertained, and their respective areas in acres were calculated. The largest population which by any chance might live on these areas in the future was estimated, *i.e.*, guessed. The future average amount of sewage proper due to such population was doubled for safety, and an additional amount added for rain, usually equalling that from .25-inch rainfall in 24 hours. If an intercepting sewer large enough to carry this total amount when flowing half full would have been too small to be entered conveniently, its size, or sometimes only its height, was increased sufficiently to afford convenient head-room.

Velocities of flow were calculated by the formula $V = C \sqrt{RI}$, with Mr. Kutter's coefficients, obtained by using .013 as the coefficient for roughness.

During the early stages of the work, the City Engineer, Mr. Davis, made a trip to Europe to examine the foreign sewerage works of best repute. Information was thus gained which was used in designing the Boston works.

In July, 1877, the City Engineer reported the results of his

preliminary survey, and on August 9 of the same year orders of the City Council were approved, authorizing, and making an appropriation for, the construction of an improved system of sewerage, in general accordance with the proposed plan, under authority of the Act of Legislature.

The City Council committed the charge of building the Main Drainage Works to a Joint Special Committee on Improved Sewerage, consisting of three Aldermen, and five members of the Common Council. This committee changed its membership every year except when one or more of its members were reelected and were again appointed on it. By city ordinance all engineering works are built by the City Engineer. The Main Drainage Works, therefore, were constructed under the direction of Mr. Joseph P. Davis, C.E., City Engineer, until his resignation in 1880, and since that date by his successor in office, Mr. Henry M. Wightman, C.E.¹

¹ Since the above was written the city has sustained a great loss in the death of Mr. Wightman. Mr. William Jackson has been elected City Engineer.

CHAPTER V.

MAIN SEWER.

THE main sewer is about $3\frac{1}{4}$ miles long, and extends from the pumping-station at Old Harbor Point to the junction of Huntington Avenue and Camden Street. Its inclination throughout its whole extent is 1 foot vertical in 2,500 horizontal. At the pumping-station the water-line of the invert, *i.e.*, its bottom, is about 14 feet below the elevation of mean low tide. From this point, in its course towards the city, the sewer passes for about a mile across the Calf Pasture Marsh, so called. The surface of this marsh is about six inches above mean high water, and, the mean rise and fall of the tide being ten feet, the average depth of excavation required for this section of work was 24 feet. Up to the junction of the South Boston intercepting sewer the main sewer is ten feet six inches in diameter. It was founded sometimes upon clay and sometimes upon sand. Figs. 1 and 2, Plate VI., show the usual methods of construction. Rubble side walls were built for the greater portion of the distance. Fig. 3 shows the bond used in the spandrels.

On this section occurred the only case during the construction of the entire Main Drainage Works in which a sewer was broken so that a portion of it had to be taken down and rebuilt. At one point, for a distance of 150 feet, the marsh mud, which usually was from five to ten feet deep below the surface of the ground, came down below the spring-line of the sewer. Owing to carelessness, on the part of the contractor, in back-filling around the haunches, or in withdrawing the sheet planks, the sewer spread six inches, and sank correspondingly at the crown. Fig. 4 shows the shape assumed at the point of maximum distortion. Although even this portion was probably stable, it was not considered wise to establish a precedent of accepting any imperfect work. Accordingly the trench was reopened, the sewer uncovered, and its arch broken down with sledge hammers.

It was found that the 12-inch Akron drain-pipe built under the sewer, to facilitate drainage of the trench during construction, was broken at this point, and the water from it, accumulated from 4,000 feet of trench, found an outlet and poured over the side walls into the invert. This water was controlled by pumps, but was found to have washed out a quantity of sand, causing a considerable cavity under the sewer platform. The limits of the cavity having been determined, five holes, ten feet apart on centres, were made through the bottom of the sewer and 3-inch wrought-iron gas-pipes were inserted into them. Two of these pipes were about 30 feet long and three others, for vents, were five feet long. Constant streams of grout, made from 47 casks of neat, quick-setting Portland cement, were forced under a 25-foot head, through the long pipes into the cavity until it was filled, as proved by the cement rising in the short pipes. The grout hardened and furnished a secure foundation. Special ribs were cut to fit the invert, which was again arched over and the trench refilled.

— Figs. 5 and 6, Plate VI., show methods of connecting man-holes with the main sewer. These structures are about 400 feet apart, and are placed alternately on one side of and over the centre of the sewer. At man-holes the arch is supported by cut-granite skewback stones. At the top of the man-holes are cast-iron frames supporting circular iron covers. The covers are perforated for purposes of ventilation. The holes are quite large, so that they are not liable to become stopped up. They also taper considerably, being larger below than they are on top. To prevent road detritus and miscellaneous rubbish from falling into the sewers, catch-pails are suspended below the covers to receive whatever may fall through the holes. The pails are of galvanized iron, well coated with tar. They can be lifted out, emptied, and replaced, as occasion demands. Wrought-iron steps were built into the man-holes during construction. These details are shown on Plate VI., Figs. 7 and 8.

Above the point where the South Boston intercepting sewers join the main sewer the latter is nine feet in diameter. For about half a mile the ground is high, but a location through



it could not be avoided without making a considerable detour. For 1,900 feet, in Mount Vernon Street, the sewer was built by tunnelling through conglomerate rock and coarse sand. The rock, where it surrounded the tunnel, presented no serious obstacle; but the sand tended to run into the excavation, and required close sheeting and heavy bracing to support it. Fig. 9, Plate VI., shows the sewer in tunnel on this section. For several hundred feet the sewer grade was near the surface of the ledge and, the latter being very irregular and covered with boulders, tunnelling operations were attended with much difficulty, and several caves occurred. For a length of 160 feet the ground was opened from the top and the sewer was built in an open trench about 45 feet deep.

The sewer in the tunnel was well built, but after completion, on removing the pumps so that the water table in the vicinity was permitted to rise above the sewer, the latter was found to leak a good deal. The leaks, however, could be successfully calked. The process consisted in raking out a joint, where a leak occurred, to the full depth of the brick and driving in sheet lead for half the depth, the remainder being filled with cement.

Excepting a section in East Chester Park, from Clapp Street to Magazine Street, the main sewer was built by contract. The laying out as a street of East Chester Park, east of Albany Street, had been contemplated by the authorities for some time, and action to that end was taken in time to permit the sewer being located there. The borings on this line showed that there were beds of marsh mud between Clapp and Magazine Streets which were from 20 to 86 feet deep below the marsh surface. As it would have been difficult to build a stable sewer in such ground, and impossible to prevent one, if built, being destroyed when the street should be filled over and around it, it was decided to fill the street to full lines and grades before attempting to build the sewer.

A contract was accordingly concluded by which the street was filled with gravel brought by the N.Y. and N.E. Railroad. So great was the settlement of this filling into the mud that over 106,000 cubic yards of gravel were required. The marsh

level for 100, or more, feet on either side of the filled street was pushed up by the filling from 8 to 14 feet high. A surcharge, 20 feet wide on top and eight feet high, was put upon the street, west of the N.Y. & N.E. Railroad, where the mud was deepest, to insure prompt settlement.

Building a stable sewer in a street so recently filled being a difficult operation, requiring methods of treatment which cannot be determined upon beforehand, it was thought best to build this section by day's labor.

As a masonry structure would have been broken when the trench was refilled, a wooden sewer was adopted (Fig. 10, Plate VI.). This consisted of an external wooden shell, formed of 4-inch spruce plank, ten inches wide, every fourth plank being wedge-shaped; the whole securely spiked and treenailed together and finally lined with four inches of brick or concrete masonry.

The depth of excavation for this sewer was from 32 to 36 feet, and the pressures were so great as to require very heavy bracing. As many as 60 braces of 8 inch $\times$ 8 inch, or heavier timber, were sometimes used for a length of 18 lineal feet of trench; and these, when taken out, were all found to be either broken, or so crippled as to be unfit to use again. Frequently the earth on one side of the trench was found to be different from that on the other, which caused very unequal pressures, so that internal bracing was necessary to maintain the sewer in its proper shape until the trench had been back-filled. It was found necessary to build the shell with a vertical diameter four inches greater than was required for the masonry lining, to allow for settlement, change of shape, and compression of the timber. The vertical diameter inside of the lining was also increased, so that, if in places the sewer should settle as a whole, the bottom could be brought to the true grade, and still leave the established sectional area.

The length of this section was 1,894 feet. Ground was first broken in August, 1879, and the work was completed in October, 1880. For excavating and back-filling the trench, machinery designed by the Superintendent, Mr. H. A. Carson, was used. The average cost per lineal foot of the completed sewer

was \$56. For several hundred feet, where the mud had been deepest, a continual slight shrinkage and settlement of the gravel filling under the sewer occurred for a year or more. The sewer itself, also, settled in a long curve, whose greatest depth below the original grade line was about 18 inches. A masonry sewer would have been broken by such movement, but the wooden one having considerable flexibility was apparently uninjured. At present (1885) the street seems to have assumed a condition of permanent stability.

In East Chester Park, from Magazine Street to Albany Street, clay was chiefly encountered, and the sewer generally consisted of a simple ring of brick-work without side walls, and its construction presented few features of special interest. As a precaution in passing within 35 feet of a large gas-holder, tongued and grooved 4-inch sheet planks were driven, and the trench was back-filled with concrete to the crown of the sewer arch (Fig. 11). In passing across the old Roxbury Canal, which had been recently filled by the city, an influx of tide-water along the loose walls of the canal and through the filling occasioned some delay and expense. The water was finally kept out by double rows of tongued and grooved sheet-piling. A side entrance and boat-chamber (Fig. 12), were built on this section, at the corner of Swett Street. The latter structure resembled a very large man-hole, with a rectangular opening from the street, 11×4 feet in dimensions. This was built to allow the lowering of boats into the sewer.

At Albany Street the east-side intercepting sewer joins the main, and above this point the latter is again reduced in size, to eight feet three inches wide by eight feet five inches high. The extra horizontal course was put in at the spring line because it was supposed to facilitate dropping and moving the centres. In East Chester Park, and Washington Street from Albany to Camden Street, the sewer was built chiefly in clay, and consisted of a ring of brick-work. For about 300 feet, however, near Albany Street, mud was found, and a foundation, consisting of a timber platform supported on piles, became necessary (Fig. 13, Plate VI.).

In Camden Street, from Washington Street to Tremont

Street, a distance of 1,391 feet, the depth of trench required would have been 26 feet. Camden Street is rather narrow, and contains sewer, gas, and water pipes. As good clay was found at a depth five or more feet above the top of the sewer, it was thought that it would be as cheap to the city, and decidedly less annoying to residents on the street, to build the sewer by tunnelling beneath the surface (Fig. 14). Working shafts were sunk about 250 feet apart, and headings in each direction driven from them. At one or two points the miners permitted the roof of the tunnel to settle slightly, by which the common sewer above was cracked, and some trouble caused by the sewage leaking into the tunnel. The main sewer was back-filled above the arch with clay, packed in under the lagging as firmly as possible. On the whole the method of construction was successful, and a well-built sewer was obtained. Its cost was \$22.52 per lineal foot.

At Tremont Street the Stony-Brook intercepting sewer is taken in. At this point, as at all other places where intercepting sewers join the main sewer, the grade of the latter rises abruptly somewhat less than a foot, or enough to maintain the established inclination on the surface of the sewage at the time of maximum flow. From Tremont Street to the present end of the main sewer, at Huntington Avenue, the sewer was built in open cut (Fig. 15), and for a large part of the distance needed side walls and piling for its support. Just west of the B. & P. R.R. another boat-chamber and side entrance (Fig. 16) were built, and a third side entrance, reached by a stone stairway leading from the sidewalk, was constructed at Huntington Avenue.

The total cost of the 3.2 miles of main sewer was \$606,031 being an average of \$36.09 per lineal foot.

CHAPTER VI.

INTERCEPTING SEWERS.

As before stated, and as shown by the plan (Plate V.), the South Boston intercepting sewer is the first to join the main sewer in the latter's course from the pumping-station towards the city proper. This intercepting sewer, by its two branches, is intended finally to encircle the peninsula on which South Boston is situated, and intercept the sewage flowing in the common sewers, which have heretofore discharged their contents at nineteen outlets, in the immediate vicinity of a dense population.

At the point of junction the grade of the intercepting sewer is 1.5 feet higher than that of the main sewer, so that the sewage in the former shall not be dammed back, and the established rate of inclination shall be maintained on the surface of the sewage in both sewers at the time of maximum discharge. In all cases where a main-drainage sewer joins another, the junction is made at a "bell-mouth" connection chamber, in which the axes of the sewers meet by lines or curves tangent to each other, so that the two currents may unite with the least disturbance to either. Sections of the "bell-mouth" junction of the two branches of the South Boston sewer, at Hyde Street, are shown by Fig. 14, Plate VII. On each intercepting sewer, just before it reaches the main sewer, is built a penstock chamber, containing a cast-iron penstock gate, by which the flow can be cut off, so that the main sewer can be entirely emptied, should it ever be desirable to do so. At such times the city sewage would be discharged at the old outlets, which are all retained and protected by tide-gates. A sketch of the penstock on the South Boston sewer is given by Fig. 6.

Up to where it divides this sewer is circular, six feet in diameter. The average depth of excavation was 20 feet. Clay or sand was usually found, and the sewer consists of a simple

ring of brick-work, 12 inches thick, though for about 350 feet, where the sand was wet and inclined to run, abutment walls of rubble masonry were used. Figs. 12 and 13 show cross-sections of this sewer. The brick invert was laid with Portland cement mortar, one part cement to two parts sand, and the arch was laid with American (Rosendale) cement mortar, one part cement to 1.5 parts sand. This was the common practice in building the main-drainage sewers, Portland cement being used in the inverts, on account of its greater resistance to abrasion. When Rosendale cement was used for building inverts, the proportion required was equal parts of cement and sand.

The inclination of this sewer throughout the greater portion of its extent is 1 in 2,000, which affords a velocity of flow sufficient to prevent deposits of sludge, but not sufficient to keep in suspension sand and road detritus. A sharper inclination would have been desirable had it been practicable to obtain one. Few of the main drainage sewers have a greater inclination than 1 in 2,000, and it was expected from the first that flushing would occasionally be required to prevent the accumulation of deposits. To provide for this, iron flushing-gates are built into the sewers at intervals of about half a mile. The first flushing-gate on the South Boston sewer is just below the fork at Hyde Street. A sketch of this gate is given by Fig. 15. Usually the gate stands above the sewer, in the man-hole. It is kept vertical by two small stop-bolts at its top. To flush the sewer the gate is lowered against its seat, built into the bottom of the sewer, and the sewage accumulates behind it as deep as the gate is high. The stops are then withdrawn and the gate raised until it clears its lower seat, when it tilts over into a horizontal position and opens a free passage for the dammed-up sewage.

The greater part of South Boston is high land, and there are but few low cellars there which are subject during rain-storms to flooding at high tide. In order that the full capacity of the sewers and pumps might be available to relieve other parts of the city, less favored in this respect, it was necessary to arrange that no more than a fixed quantity of sewage should ever be received by the main sewer from the South Boston

intercepting sewer. To accomplish this a "regulator" was built into the intercepting sewer just below its last connection with a common sewer, at Kemp Street.

A sectional plan and elevation of this machine, and of the chamber containing it, is given by Fig. 9, Plate VII. As will be seen, the apparatus is very simple, and consists of stop-planks, closing the sewer from its top down to about the ordinary dry-weather flow line, the sewer below the planks being lined with a cast-iron gate frame, or seat, curved to fit the invert, and also vertically to correspond with the curve of motion of a cast-iron valve, which plays up and down in front of it. The valve is held by two cast-iron levers, pivoted by a 3-inch wrought-iron shaft in two bearings, the other ends of the lever being connected by vertical arms to a 3-inch square bar. To the ends of this bar are fastened two boiler-plate floats, placed in wells on either side of the sewer. To avoid disturbance to the motion of the floats, by waves caused by the rush of sewage under the valve, water is brought to the wells through a 5-inch pipe, as shown, from a point 50 feet below the regulator.

The connection between the valves and the floats can be so adjusted that the former will begin to close when the surface of sewage in the sewer has reached any desired height. As the floats rise the valve descends until the opening below it is just sufficient to let enough sewage pass to maintain the allowed depth of flow in the sewer. Should the amount of rain-water from low districts, reaching the main sewer through other intercepting sewers, exceed the capacity of the pumps to control it, the main sewer fills, and its sewage backs up into the South Boston sewer, and still further raises the floats. The opening under the stop-planks is thus entirely closed, and all of the common sewers above discharge at their old outlets, and continue to do so until the amount of water reaching the pumps can be controlled by them.

Above where this sewer divides, at Hyde Street, the branch which turns to the right, and skirts the southerly margin of South Boston, is egg-shaped, four feet six inches high by three feet wide (Fig. 11, Plate VII.). After passing under the

Old Colony Railroad the shape is changed somewhat (Fig. 3). At Vinton, Vale, and other streets, common sewers are intercepted. Fig. 7, Plate VII., shows the connection with the Vale-Street sewer, and may stand as a type of such connections between common and intercepting sewers, wherever no regulation of the amount to be received from the former is required. Nearly every individual case presented special conditions, which necessitated some modification of the method of construction; but the general plan was the same in most cases, and its features are shown in this case.

A sump hole, two feet deep, into which the sewage falls, is first built in the common sewer. Into the bottom of this sump is built a short section of iron pipe (Fig. 5), from 12 to 24 inches in diameter, protected by a cast-iron flap-valve. Ordinarily this valve stands open, but can be closed if it is desired to break the connection between the two sewers. The bottom of the sump, around the pipe, is rounded off with strong Portland cement concrete, so that there shall be no corners in which deposits can lodge. The sewage passes to the intercepting sewer through a short branch connecting with the lower end of the iron pipe.

Beyond the sump the common sewer is provided with a chamber containing a double set of tide-gates. These gates give a clear opening of from two to four feet diameter. Each set of gates is hinged to a cast-iron ring, or gate seat (Fig. 8), which is built into the brick-work. The two wooden gates close against each other. To make tight joints the bearing surfaces of the gates are covered with strips of rubber about three-eighths of an inch thick. The gates are inclined somewhat, so that they are self-closing.

From the main sewer to the Old Colony Railroad this intercepting sewer was built by contract, at an average cost of \$12.68 per lineal foot. From the railroad to H Street it was built by day's labor, and cost \$13.25 per lineal foot. On Ninth Street, between Old Harbor Street and G Street, for a distance of about 800 feet, the sewer location crossed a beach which was several feet below high-tide level. No coffer dam or other protection was used in this place, but construction was carried

on only when the tide was down. When the sea rose it overflowed and filled the trench. When it again fell the water in the trench was let off through the sewer already built, to pumps at the pumping-station, and work was resumed. From H Street to N Street, on Ninth Street, the sewer was built by contract. For about 1,000 feet, near K and L Streets, the average depth of the trench was about 27 feet. The sewer was nearly circular, three feet wide and three feet two inches high (Fig. 1, Plate VII.). This section was among the earliest built, and its design is not in accord with later practice. It might have been made much more convenient for workmen to enter, at slight additional expense, by giving it a greater vertical diameter. Its fall is 1 in 1,666 $\frac{2}{3}$.

From the point of division on Hyde Street the sewer which turns to the left, and follows the westerly shore of South Boston, is egg-shaped, five feet six inches by four feet nine inches, up to the Old Colony Railroad crossing, on Dorchester Avenue. A timber platform and rubble masonry side walls were required for the entire distance, and the usual cross-section of this sewer is shown by Fig. 10, Plate VII. This section was built by contract. Its length is 3,350 feet; the average depth of excavation was about 24 feet, and the average cost per lineal foot was \$16.85.

After taking in the B-Street sewer the intercepting sewer changes its shape (Fig. 3), and continues in Dorchester Avenue, passing under the N.Y. & N.E. Railroad, and turns into Foundry Street, which it follows to its end, at the corner of Dorchester Avenue and First Street. Considerable difficulty was encountered in passing under the abutments of the bridge on Dorchester Avenue, over the N.Y. & N.E. Railroad. These were underlaid by running sand, and the northerly abutment over the sewer, which had been built without mortar, had to be taken down. Under the tracks of the same railroad, head-room being limited, the shape of the sewer was altered (Fig. 2), so that there should be no danger of its interfering with, or being injured by, repairs to the road-bed. This section of sewer is 2,820 feet long, and its average cost per foot was \$19.25.

The second large intercepting sewer which enters the main sewer, had its point of connection at the intersection of East Chester Park and Albany Street. It is called the East Side intercepting sewer, and is located in streets following the easterly margin of the city proper for a distance of about $2\frac{1}{4}$ miles. In Albany Street, from East Chester Park to Dover Street, a distance of 4,524 feet, the sewer is nearly circular, with a vertical diameter of five feet eight inches, and a horizontal one of five feet six inches. The inclination is 1 in 2,000. The average depth of excavation for this section of work was 24 feet, and, as marsh mud and peat extended from near the surface of the ground to a depth always considerably below the bottom of the sewer, piles were required to furnish a secure foundation. A timber platform was fastened to the tops of the piles, and on the platform the sewer, with its rubble masonry abutment walls, was built. The bottom of the excavation was about 6.5 feet below the elevation of low tide, and considerable trouble was experienced from sea-water making its way into the trench, especially in places where old sea-walls and other such obstructions were encountered. The mud on the sides of the trench exerted much lateral pressure, and close sheet-piling and heavy bracing were necessary. Opening so deep a trench in such material drained the water out of the adjacent soil, rendering it spongy and somewhat compressible, so that the whole street settled and had to be resurfaced and repaved. This section was built by contract. One firm of contractors gave up the job, and the work was re-let under provisions of the contract. The average cost per lineal foot of the completed sewer was \$26.16.

The first common sewer taken in by the interceptor is that on Concord Street. This sewer drains a district in which the cellars are not subject to flooding from rain-water during high tides. It was not necessary, therefore, to let this sewer discharge into the interceptor an amount of sewage in excess of its ordinary maximum dry-weather flow, and temporarily, during rain-storms, the whole dilute contents of the sewer could, without injury, be permitted to discharge into the bay at the old outlet. An arrangement to effect this was desirable, because, during very heavy rain-storms, the whole capacity of the inter-

cepting sewer might be needed to afford relief to sewers draining low districts beyond Concord Street.

Accordingly the connection between this sewer and the intercepting sewer was made through a chamber containing a small regulating apparatus, designed to control or cut off the flow automatically. Figs. 1 and 2, Plate VIII., show sections of this apparatus and its arrangement. Eight similar appliances, with slight modifications in the methods of arrangement, were used in connection with the same number of common sewers.

The operation of the apparatus will be understood from an examination of the figures. Under ordinary circumstances the sewage falls into a sump, and thence passes to the regulating chamber, which it enters through a cast-iron nozzle. This nozzle is circular, 12 inches in diameter at its upper end, and rectangular 20×6 inches at its orifice. In front of the orifice plays a cast-iron valve, moved by a float in a tank set in the floor of the chamber. The water in the tank stands at the same elevation as that in the intercepting sewer, a 4-inch iron pipe connecting one with the other. The apparatus can be adjusted so that the valve will begin to close and cut off the flow of sewage when the water in the intercepting sewer reaches any desired depth. When not cut off, the sewage flows around the tank and passes on through an opening at its further end.

The second common sewer taken in is that in Dedham Street. This sewer drains a district which used to suffer greatly from flooding during rain-storms. In order to afford relief this sewer was connected directly with the interceptor by a branch two feet in diameter, the inlet to which is never closed.

The third sewer taken in is that in Union Park Street. The district drained by it has suffered but slightly from wet cellars, and that only during severe storms and very high tides. The flow from this sewer was regulated in the same manner as that from the Concord-Street sewer, but the apparatus was so adjusted that it cuts off the flow later than in the case of most other sewers, and only when the intercepting sewer is nearly full.

The fourth common sewer met with is that in Dover Street.

This drains a low district, and a free connection, two feet in diameter, was made with it. According to the usual practice in such cases this sewer would have been connected with the interceptor at or near the point in Albany Street where their two locations intersect. But it was found in examining the city sewers, with reference to connections with them, that the Dover-Street sewer was not in condition to be intercepted at any point east of Harrison Avenue. Between that street and its outlet it is a rectangular wooden structure, 5×6 feet in dimensions, placed close to an old stone retaining-wall and surrounded by loose stone ballast. It is considerably broken, so that the tide-water from the bay which ebbs and flows about the wall and in the ballast has free access to the sewer, and would have flowed into the intercepting sewer, and so reached the pumps. From Harrison Avenue westerly, the Dover-Street sewer was built of brick, and was tight so that seawater could be excluded from it by tide-gates. Accordingly the connection was made west of Harrison Avenue, and a 2×3 feet oval branch sewer (Fig. 3), 588 feet long, was built from that point to convey the sewage to the intercepting sewer at Albany Street.

Above Dover Street are few districts which suffer from flooding. Accordingly a large regulating apparatus, to control the flow from above, was built into the intercepting sewer at this point. It resembled that on the South Boston sewer, before described, and shown on Plate VII. by Fig. 9.

From Dover Street to its upper end on Atlantic Avenue the East Side sewer was built by day's labor, under a superintendent appointed by the city. This was done because above Dover Street the sewer location was confined to crowded thoroughfares, in which peculiar management was required to prevent serious obstruction to travel and to the business of abutters; and also because, operations being principally carried on in filled land, beds of dock mud, old walls, wharves, and other obstructions were continually encountered, requiring frequent changes in methods of construction which could not be foreseen and provided for in the specifications of a contract.

From Dover Street the sewer location extends in Albany



Street to Lehigh Street, at which point it enters private land, and crosses the freight and switch yards of the Boston and Albany, and Old Colony Railroads, to Federal Street near the bridge, a total distance of 2,331.5 feet. In Albany and Lehigh Streets are the tracks of a Freight Railway Company, and in the railroad yards are about 40 lines of rails in constant use, which it was very important should not be disturbed. The whole section of work is in filled land, underlaid by beds of mud from 5 to 20 feet deep, below the bottom of the sewer, which is itself several feet below the level of low tide. At different points obstruction in the shape of old walls and wharves were encountered, which admitted sea-water freely to the trench, so that, as a rule, work could only progress during low stages of the tide.

The sewer is oval, five feet high (Fig. 4), and generally required piling for its support. It is built partly of wood, lined with two inches of concrete, and partly of brick-work resting on a solid cradle of wood, six inches thick. Travel upon the streets was not interrupted, and with considerable difficulty the freight-railway tracks were supported and maintained. As it would have been impossible to have had an open trench through the Albany and Old Colony Railroad yards without interfering with their traffic, operations at that point were carried on entirely below the surface. The tracks were supported by stringers, and the spaces between them floored over. By the use of special machinery all the earth excavated or refilled, as well as materials for constructions, was conveyed by tracks suspended below the floor. The trench was well braced, and its sides protected by lag-sheeting, which, together with the piles driven to support the sewer, were all put in place without encroaching upon the surface. It is believed that not a single train was delayed, nor any inconvenience caused, by these operations. The average cost of this section of sewer was about \$31.26 per lineal foot.

In Federal Street, and Atlantic Avenue to its end at Central Street, the intercepting sewer is oval, four feet six inches high by two feet eight inches wide. Fig. 5, Plate VIII., shows the usual mode of construction. Federal Street contained double horse-

railroad and single freight-railway tracks, and beneath its surface were one sewer, two water pipes and two gas pipes. Beds of dock mud extended from 5 to 20 feet below the bottom of the new sewer, and old dock walls and timber structures were frequently encountered. A location on the east side of the street was found to be most practicable, and the sewer was built by methods which left the roadway open for travel. By flooring over the trench at intervals, passages were maintained through the excavating machine (shown on Plate XXV.) to the yards and wharves bordering Fort Point Channel.

The freight-railway tracks were shifted towards the centre of the street, and were used during the day for the passage of horse-cars in one direction. Bricks, cement, and other material were piled on the outer edges of both sidewalks where they would cause least inconvenience, and always so as to leave a clear passage-way four feet wide. Endeavors were made to cause the least possible annoyance to corporations and individuals; and in general these efforts seemed to be appreciated and reciprocated by the public, so that complaints were rare. This section of work was 5,159 feet long. The average depth of excavation was about 21 feet, and the average cost of completed sewer was \$15.06 per lineal foot. The Stony-Brook intercepting sewer joins the main sewer at the intersection of Camden and Tremont Streets. This sewer intercepts the sewage which formerly emptied at seven outlets, into Stony Brook, and thence found its way into the Back Bay. In Tremont and Cabot Streets, from Camden to Ruggles Street (Plate V.), a distance of 2,135 feet, the sewer was built by contract. The rate of inclination is 1 in 700, and the average depth of excavation required was 21 feet. The sewer is nearly circular, four feet six inches wide by four feet eight inches high, and is chiefly founded on clay, so that side walls were only needed for about 300 feet, and the average cost per lineal foot, including inspection, was \$11.97. The customary iron penstock gate was built into the sewer just above the bell-mouth connection chamber by which it joins the main.

As the territory drained by the sewers which empty into Stony Brook is high land, a large automatic regulating appara-

tus, similar to the one shown on Plate VII., was built into the intercepting sewer at Ruggles Street, by means of which the flow is partly or wholly cut off during severe and continuous rain-storms. Above the regulator is a three-way bell-mouth chamber (Fig. 10, Plate VIII.), from which radiate three principal branch sewers. The centre or main branch, about $4\frac{1}{2}$ feet in diameter, is 1,700 feet long, and intercepts the sewage formerly discharging into the brook by outlets at Elmwood and Hampshire Streets. This sewer passes twice under the brook, at so low an elevation that it preserves its regular grade and shape. The other two branches are built just large enough to enter, being 2×3 feet, egg-shaped, with the smaller end down. These also cross twice under the brook, at Tremont Street and at Ruggles Street. Including the regulating chamber, and all sewers above it, this section of work was built by the day, under the City Superintendent, Mr. H. A. Carson. There were built in all 4,229 lineal feet of sewers, including 415 feet of 15-inch pipe. The average cost per foot of the whole was \$14.30. A considerable portion of the 2×3 feet sewers was built during the winter of 1880-81. The sewers were from 14 to 19 feet below the street surface, and the excavation was done by tunnelling from pits about 10 feet apart. The outlets of the city sewers being below the level of high tide, in order to prevent back-water reaching the intercepting sewer, it was necessary to build gate-chambers just beyond the points of interception, each chamber containing a double set of tide-gates.

The last of the large intercepting sewers joins the main sewer at its present end at the intersection of Camden Street with Huntington Avenue (Plate V.). It is commonly called the West Side intercepting sewer, and is located in streets bordering the westerly margin of the city proper, and intercepts the sewage which formerly discharged into Charles River. This sewer is about $3\frac{1}{2}$ miles long, and its inclination from end to end is 1 in 2,000.

From the main sewer to Beacon Street, and in that street to Charles Street, a distance of 9,325 feet, the West Side sewer was built by day's labor, at an average cost of \$13.35 per lineal

foot. This section of work includes, besides the customary man-holes, six common-sewer connections, five small regulators, one side entrance, one penstock, and three flushing-gates. The usual form of this sewer is shown by Fig. 8, Plate VIII. It is egg-shaped, five feet six inches high by four feet nine inches wide. It will be noticed that the usual position given to an egg-shaped sewer is reversed in this case, the larger end of the egg forming the invert. This position was adopted because, while affording convenient head-room, it kept the flow line as low down as was practicable. As the flow in this sewer is always a foot or more deep, the hydraulic mean depth, and consequently the velocity of flow, is greater than it would have been had the smaller end of the sewer been below.

A case of slight injury to this sewer may be worth noticing. When the sewer was built on the line of Falmouth Street that street had not yet been filled and graded, and the mud and peat, which underlay the marsh surface in that locality, sometimes extended down below the top of the sewer. About a year afterwards the street was graded with gravel about seven feet high above the original surface of the marsh over the sewer. One side of the street was filled before the other, and the unequal pressure which resulted was transmitted to the sewer, and caused its arch to bulge, as shown by Fig. 12. Fortunately the amount of distortion was not sufficient to endanger the sewer's stability, and the crack was pointed with Portland cement.

In Hereford Street, for a distance of 282 feet, the sewer location passed under a freight-yard of the Boston & Albany Railroad, in which were about 20 lines of track. Piles were driven and stringers placed to support these tracks, and nearly all of the sewer building operations were carried on beneath the surface of the ground, so that the traffic of the railroad was not interfered with. At this point, and beyond the railroad location for a total length of about 800 feet in Hereford Street, a common sewer was built in the same trench, directly above the intercepting sewer. This was done by an arrangement with the City Sewer Department, which designed and paid for the upper sewer. A cross-section of the two sewers, showing their arrangement, is shown by Fig. 9.

In Beacon Street, for a distance of 590 feet in the vicinity of Exeter Street, 22 old stone walls, from five to twelve feet thick, were encountered and had to be cut through. These walls constituted the sluiceway of the old mill-dam, and their removal caused considerable delay. The cost of excavation per lineal foot of trench, 20 feet deep in this street, varied from \$3.94 to \$14.49. The section from Camden to Charles Street was built in 1878. During a portion of the season work was carried on day and night at two different points. The largest number of men and boys employed at any one time was 369. The rate of progress varied greatly; where no special obstacles were met, 108 feet of completed sewer was built each 24 hours.

On Beacon Street the large common sewers in Hereford, Fairfield, Dartmouth, and Berkeley Streets are intercepted. The sewage from each of these sewers passes to the intercepting sewer through a chamber in which is a small automatic regulating apparatus, similar to the one shown on Plate VIII., so adjusted as to cut off the flow whenever the water in the intercepting sewer exceeds an established depth. The sewers just mentioned are too low to pass over the intercepting sewer, and a somewhat different method of construction was necessary in connecting them. The arrangement at Berkeley Street is shown by Fig. 13, Plate VIII.

A secondary intercepting sewer was built in Brimmer Street, which collects all of the sewage flowing westward from Beacon Hill, and conveys it to the principal intercepting sewer in Beacon Street. For the sake of economy and simplicity, the old outlets of the common sewers in Revere, Pinckney, Mt. Vernon, Chestnut, and Beacon Streets were abandoned, and the total flow from these sewers, including rain, is taken by the new Brimmer-Street sewer, a single storm overflow being provided at Back Street. The construction of the Brimmer-Street system involved the building of 1,456.5 feet of oval brick sewers, varying from 2×3 feet to 3×4 feet 6 inches in diameter; also the rebuilding of about 556 feet of common sewers, which were found to be too low or otherwise defective. The flow from the Brimmer-Street sewer into the intercepting sewer in

Beacon Street is regulated in the same manner as that from the ordinary city sewers.

A little beyond Brimmer Street a large common sewer, which comes from the south across the Public Garden, is intercepted. This drains what is called the Church-Street district, comprising low territory, in which are many cellars which used often to be inundated. Sewage from this sewer, therefore, is taken directly into the intercepting sewer without the intervention of any regulating apparatus.

On Charles Street, from Beacon to Cambridge Street, a distance of 1,832 feet, the sewer was built by contract. It is egg-shaped, 4×4.5 feet in diameter (Figs. 6 and 7), and cost \$10.10 per lineal foot. This was the only section of the West Side sewer which was built by contract. In excavating the trench many of the hollow-log water-pipes of the old Jamaica Pond Aqueduct Company were found in a perfect state of preservation. A house-drain was found which the drain-layer had connected with one of these water-pipes, although the street sewer was but a few feet distant. The log had but three inches' bore, and, of course, led to no outlet.

At the intersection of Cambridge and Charles Streets a large automatic regulating apparatus, similar to the one shown on Plate VII., was built into the sewer, to control the flow from above. The excavation in which the chamber for this apparatus was built was 30 feet square; but, by flooring over the top of the excavation, and supporting the various lines of street-railway tracks at that place, travel was not impeded, all building operations being carried on below the surface of the street.

From Cambridge to Leverett Street, a distance of 2,150 feet, the intercepting sewer is oval, four feet six inches by three feet in diameter. It is of brick-work, eight inches thick, and usually required a timber cradle support. The work on this section presented the usual difficulties met with in excavating through filled land, in the way of old obstructions and the free access of tide-water. By a rather curious coincidence, for a distance of about 500 feet, the remains of an old wharf or bulkhead were found, with longitudinal rows of piles within the trench in such positions that, by cutting them off at the proper elevation, they

served as a support for the sewer, in the place of new piles which would otherwise have been necessary. Seven hundred and one feet, in all of the Fruit-Street and Livingstone-Street sewers, which were too low to be intercepted, were replaced by 2×3 feet oval brick sewers. The private sewer from the Massachusetts General Hospital was also too low to be intercepted. This was found to be a rectangular wooden scow, 2.5×2.5 feet in diameter, with its bottom at low-tide level. The Trustees of the hospital themselves replaced it with a 10-inch drain-pipe at a higher elevation.

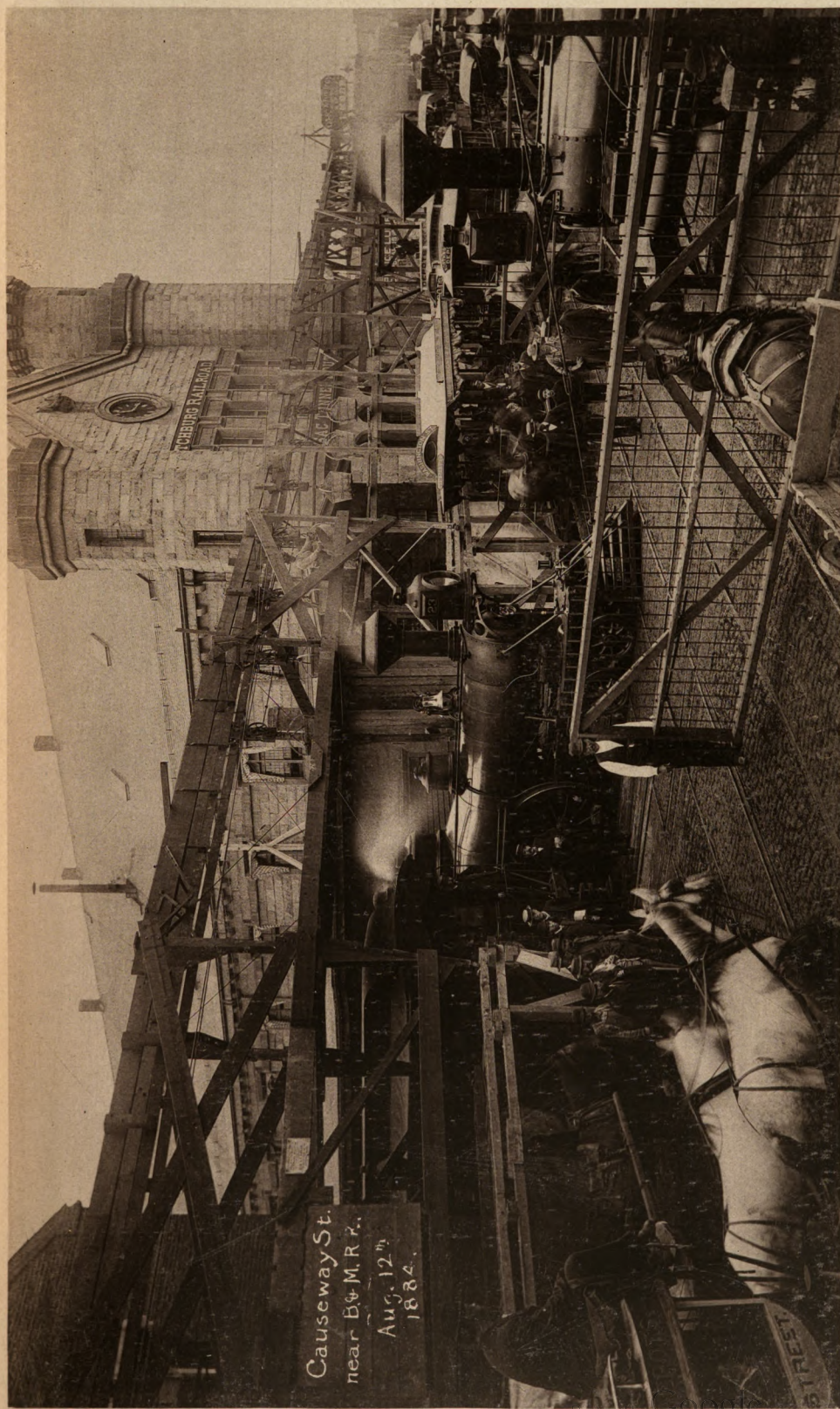
From Charles Street to its upper end at Prince Street, a distance of 3,571 feet, the West Side sewer maintained, with rare exceptions, an even size, of three feet wide and four feet six inches high. The arch consisted of eight inches of brick, and the invert was generally made with four inches of brick resting on a timber cradle, also four inches thick. The common sewer in Lowell Street, which was a large, flat-bottomed wooden scow, was too low to be intercepted. It was accordingly abandoned, and all branch sewers and house-drains were connected directly with the intercepting sewer. To facilitate making these connections the intercepting sewer was located exactly on the line of the old sewer. The top planks of the latter were removed, but its side planks were retained, and the new sewer, with its width reduced to two feet eight inches, was built between them. The flow of sewage was maintained during construction through channels above the floor of the old sewer and below the bottom of the new one, which was supported on timber saddles (Fig. 14, Plate VIII.).

Causeway Street is one of the most crowded thoroughfares of the city. It contains two lines of track for horse-cars and one for freight-cars. On its north-westerly side are the depots of three railroads, with no outlet for their passengers and freight except into this street. The tracks of another railroad cross the street. The territory traversed by the street is all made land, consisting of loose materials filled upon a mud bottom.

It was with some apprehension of trouble that work was begun on this section. The most difficult feature of the work was so to conduct it that travel should not be seriously impeded.

Owing to the skill and care of the superintendent and his subordinates, and to the appliances used for handling the earth and other material, the sewer in this street was built within four months, without closing any portion of the street to travel, and with the minimum of inconvenience to the public. At street-crossings and entrances to railroad-yards, work was carried on below timber platforms, or bridges, without encroaching upon the street surface. In crossing the Boston and Maine Railroad tracks, the excavating apparatus, with its steam-engine, was so elevated as to leave head-room for the passage of trains. Plate IX. is from a photograph taken at this point.

As a precaution, where the foundation seemed insecure, the vertical diameter of the sewer was increased by six inches, so that, should slight unequal settlements occur, the invert may be brought to its true grade without lessening the desired size of the sewer. For about 76 feet, to avoid interfering with the street surface, the intercepting sewer was built entirely within an abandoned common sewer (Fig. 15, Plate VIII.). At the upper end of the intercepting sewer, at Prince street, the grade of the invert is about four feet above mean low water, which is the highest elevation of any portion of the Main Drainage System. At this point a direct connection with the harbor has been made, which is closed under ordinary circumstances by a three feet square penstock gate. By opening this gate at the time of high tide the sewer can be thoroughly flushed.



Causeway St.
near B. & M. R. R.
Aug. 12th
1884.

CHAPTER VII.

PUMPING-STATION.

As before stated, and as shown by the plan (Plate V.), the Main Drainage Pumping-Station is situated at Old Harbor Point, on the sea-coast in Dorchester, about a mile from any dwelling. In flowing by gravitation to this point the sewage has descended, so that it is from 11 to 14 feet below the elevation of low tide. To reach its final destination it must flow about $2\frac{1}{2}$ miles further, to Moon Island, and be high enough, after arriving at the storage reservoir on the Island, to be let out into the harbor at the time of high water. That it may do this it must first be raised by an average lift of 35 feet.

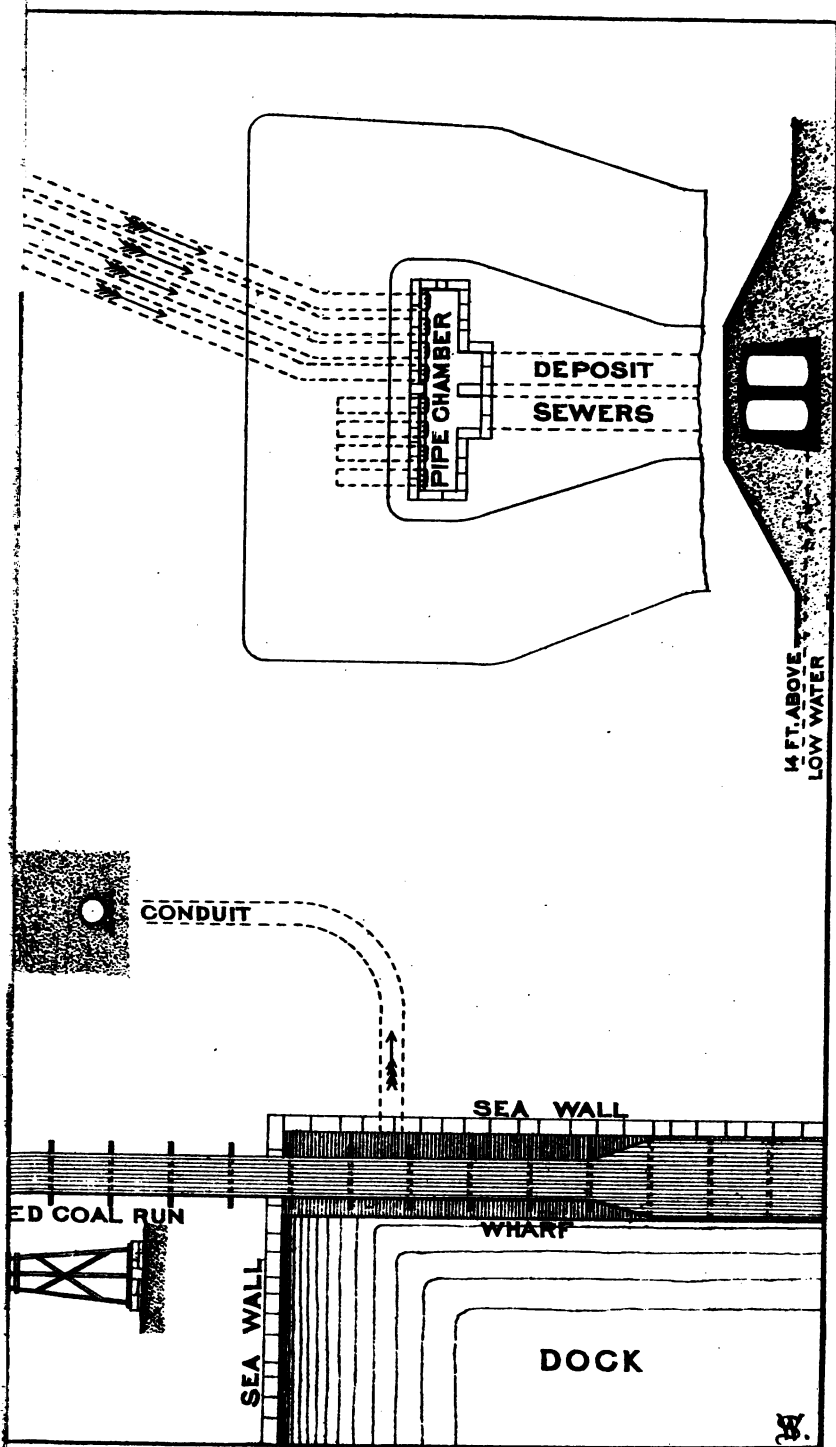
The essential parts of the pumping-station are: a filth-hoist (so called), where the sewage passes through screens to remove solid matters which might clog the pumps; pump-wells, into one or more of which the sewage can be turned; pumping-engines to raise the sewage; an engine-house to protect the engines; a boiler-house, containing boilers to furnish steam power; a coal-house to store a supply of coal, and a dock and wharf, where vessels bringing coal can be unloaded. The position and arrangement of these principal structures and apparatus are shown on Plate X.

The filth-hoist is a solid masonry structure, extending from the surface of the ground down to below the main sewer. Its inside dimensions are 25×32 feet, and its exterior walls are from 4 to 5 feet thick, founded upon two courses of 10-inch timber. In excavating for building the filth-hoist, the ground, which consisted of wet sand, was held by round wooden curbs. The total depth of excavation was 35 feet, and the upper 12 feet were dug without bracing to natural slopes. Below this, three tiers of 4-inch sheet planks, each 10 feet long, were driven, and were braced by circular ribs. The three curbs were 71.61 and 57 feet in diameter, respectively, and by this method of

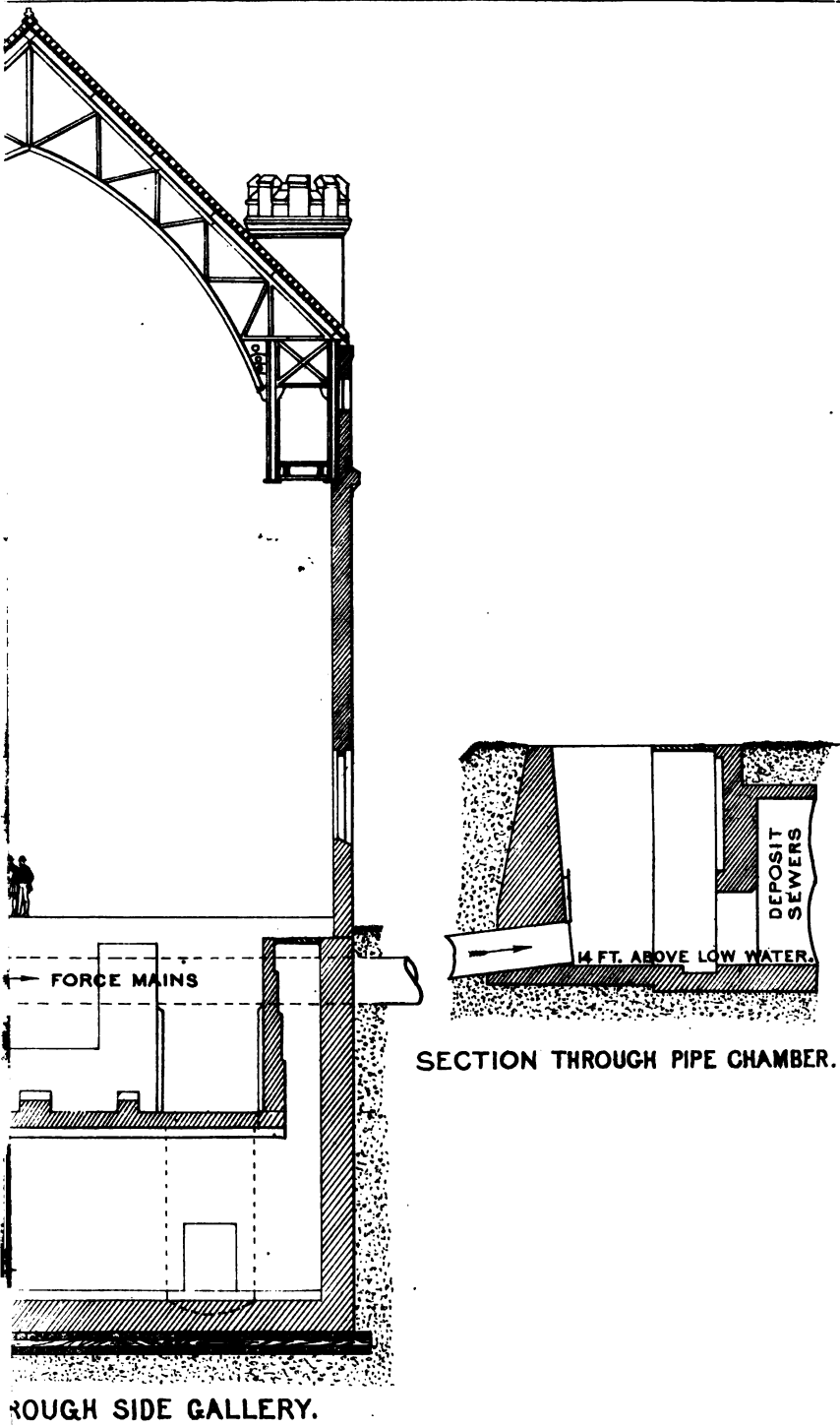
bracing an unobstructed space was secured for building the masonry.

As will be seen by referring to Plates X. and XI., the main sewer passes through the westerly foundation wall of the filth-hoist. At this point the sewer has granite voussoirs cut to form a bell shaped opening. Facing the sewer opening are two gate-openings, protected by iron penstock gates, 7×6.5 feet each, through one or both of which the sewage flows. These gates are counterbalanced and are moved by hydraulic pressure derived from a city water-pipe. The pressure is sufficient to move them freely; but to start them when down, with a head of water against them, a hydraulic force pump is added, by means of which the initial pressure can be increased to any extent required. Beyond the gates the structure is divided longitudinally by a brick partition wall into two parts, in each of which are chambers containing two independent cages, or screens, one before the other. The cages are rectangular in shape 7 feet 8 inches high, 7 feet $3\frac{1}{2}$ inches wide, and 3 feet $4\frac{1}{4}$ inches deep. They are shown in detail by Fig. 4 on Plate XIV. Their backs, sides, and tops are formed of $\frac{3}{4}$ -inch round iron rods, with 1-inch spaces between them. The cages are counterbalanced, and are raised and lowered by four small steam-engines. The steam for these engines, as well as for heating purposes, is brought underground from the boiler house. The superstructure of the filth-hoist is 30×37 feet outside dimensions, and is built of quarry-faced granite dimension-stones, lined inside with brick. A view of the outside of this building is shown at the left side of Plate XVII. Plate XII. is from a photograph taken inside of the filth-hoist when one pair of cages was raised. It gives a general idea of the arrangement of the hoisting machinery.

After passing through the cages the sewage is conveyed by one or both of two sewers, nine feet in diameter each, to galleries on either side of the engine-house substructure, from which galleries it can be admitted through gate openings to one or more pump-wells, situated between the galleries. The bottom of the pump-wells is 19.5 feet below low-tide level and 36.5







feet below the surface of the ground. From the wells the sewage is raised by the pumps to its required elevation.

The complete design of the pumping-station, as indicated on Plate X., consists of an engine-house, two boiler-houses and a coal-house, so arranged as to include a court-yard. The buildings are to be of dimensions suitable for containing eight pumping-engines with their boilers and other appurtenances. Only the portions of these buildings shown on the plan by full lines are at present constructed or needed.

The foundation walls of the engine-house aggregate about 350 feet in length. They are 37.5 feet in height and nine feet thick at the bottom, where they rest on a timber platform, 24 inches thick, which also extends under the whole building, and furnishes a foundation course for the piers which support the engines. To build the exterior walls trenches 16 feet wide were first excavated. A core of earth was left inside these trenches until the walls had been erected, when it was removed to make place for the pump-wells and engine foundations. The exterior retaining and foundation walls were built of granite, and, although called rubble masonry, yet, owing to the sizes and shapes of stones used and the care taken in selecting and laying them, the work more nearly resembles a fair quality of roughly coursed block-stone work.

The pump-wells and engine foundations are built chiefly of brick, but contain in addition about 300 dressed granite stones. These stones are used for copings, as bearings for holding-down bolts, for lining gate and other openings, etc., etc. There are nine iron gates, with suitable attachments and shafting, operated by two small steam-engines. Eight of these gates, 4 feet 9½ inches by 6 feet 3½ inches each, control the flow of sewage from the side galleries into the four pump-wells. Another gate, 4 × 4 feet square, controls the admission of salt water from the salt-water conduit.

This last-mentioned structure, as shown by the plan (Plate X.), is a solid masonry conduit, with its bottom six feet below the elevation of low tide, and connects tide-water at the dock with one of the engine-house galleries. Its office is to conduct salt water to the engine-house for use in the condensers, and

also to furnish an additional supply of water to the pumps for flushing or other purposes, whenever the amount of sewage received from the main sewer is insufficient for such purposes.

As has been stated, the sewage is elevated to heights (depending at any time upon the depth of sewage in the reservoir) which average about 35 feet.

As the city sewers receive rain-water, and as it is desired to take as much of this as possible, especially from certain districts, it follows that during short periods of time, when it rains, very much greater pumping capacity is needed than is usually sufficient. There must, therefore, be a pump, or pumps, to run continuously, and others to run only when it rains or thaws.

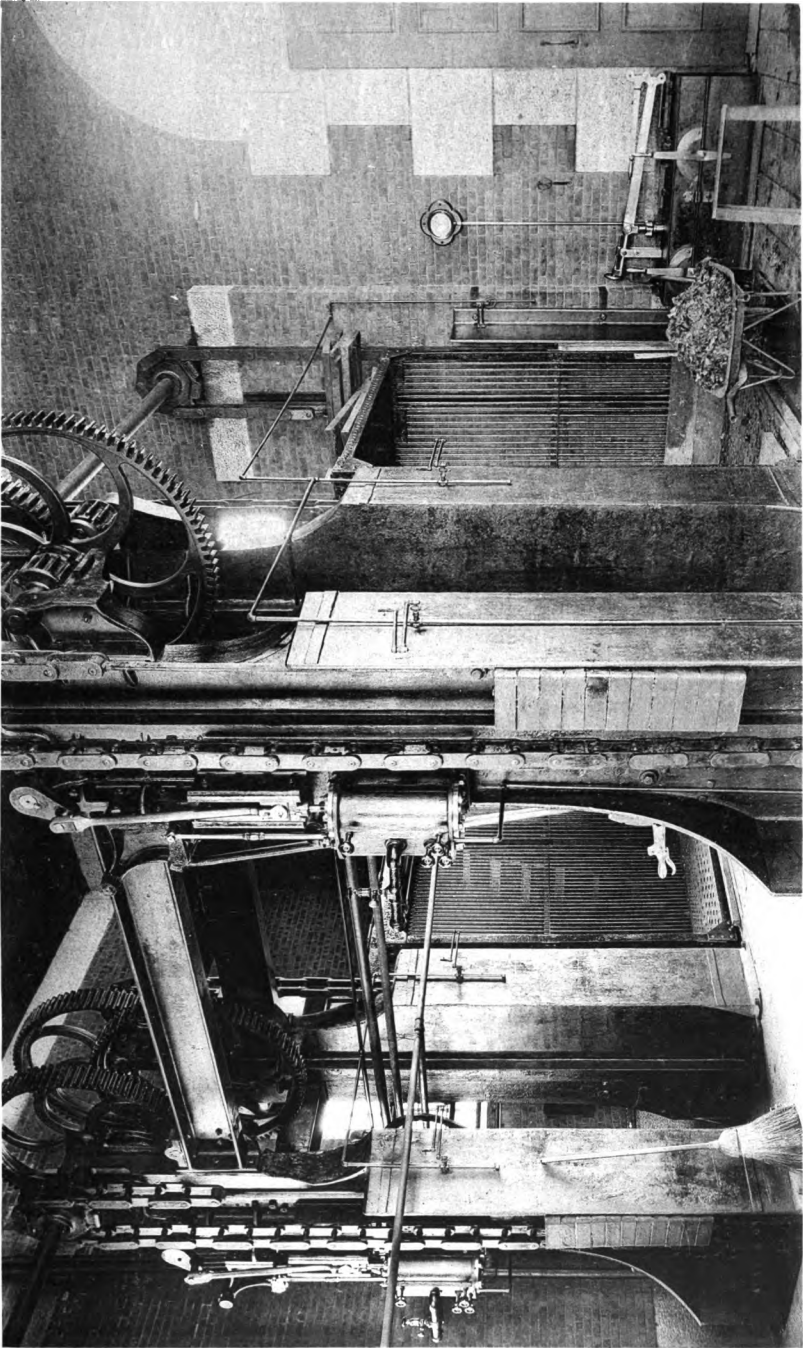
The chief item of expense in pumping is the cost of fuel. For the sake of economy the pumping engines for continuous service must do their work with as little consumption of fuel as possible, and to accomplish this an expensive machine can be afforded. For the engines which run only occasionally cheaper machines are more economical, the saving in interest on the first cost more than compensating for the extra fuel consumed by them. The pumping plant of the Boston Main Drainage Works includes two expensive high-duty engines and two cheaper lower-duty engines.

The high-duty engines were designed by Mr. E. D. Leavitt, Jr., on general specifications prepared by the City Engineer, Mr. Davis. They were built by the Quintard Iron Works, of New York, and cost about \$115,000 each. A plan and elevation of one of them is given on Plate XIII.

As will be seen, it is a compound beam and fly-wheel engine, working two single-acting plunger-pumps. The steam cylinders are vertical and inverted, their axes coinciding with those of the pumps below them, the pistons of the engines and plungers of the pumps being connected in the same line with the ends of the beam.

In designing these engines particular attention was given to the following conditions:—

First. The distribution of the weight of the engine so as not to produce concentrated pressure on any part of the foundations.



Interior of Filth-Hoist with one pair of cages raised.

Second. Great strength in the details and combinations of the parts, to render the liability of breakage a minimum.

Third. A proportion of the wearing surfaces such as will allow of an uninterrupted running for extended periods, with the least wear.

Fourth. Easy accessibility of all the parts for examination, repairs, and renewals.

Fifth. An adaptation of the pumps and their valves to the peculiar duty required of them, *i.e.*, to allow the passage of rags, sticks, and such other small bodies as will not be detained by the filth-hoist; and, in addition, a construction which will admit of the easy removal of an entire pump or any of its parts, without disturbing any important part of an engine.

Sixth. A high degree of economy in the consumption of coal.

The following are a few of the leading dimensions:—

Diameter of high-pressure cylinder, $25\frac{1}{2}$ inches.

Diameter of low-pressure cylinder, 52 inches.

Diameter of plunger, 48 inches.

Stroke, 9 feet.

Distance between centres of cylinders, 15 feet 2 inches.

Radius of beam to end centres, 8 feet 3 inches.

Radius of crank, 4 feet.

Diameter of fly-wheel, 36 feet.

Weight of fly-wheel, 36 tons.

Nominal capacity, 25,000,000 gallons a day.

Speed for capacity, 11 strokes per minute.

Steam at a pressure of about 100 pounds is admitted from the supply-pipe, A (see Plate XIII.), through the side-pipe, B, to the steam-chests of the high-pressure cylinder, C. The distribution of steam is effected by gridiron slide-valves, having a short, horizontal movement imparted by revolving cams, D, fixed on a horizontal shaft, E, running along the bases of the cylinders, and driven by the crank-shaft through suitable gearing, F. The steam is cut off by the further revolution of the cam. The cut-off is adjustable, and controlled by the governor, G.

After expanding to the end of the stroke the steam passes

through the exhaust steam-chests to reheaters, H. These are cast-iron boxes, each containing about 750 $\frac{3}{4}$ -inch brass tubes, two feet nine inches long. These tubes are filled with high-pressure steam, and in circulating about them the working steam is thoroughly dried.

From the reheaters the steam is admitted to the low-pressure cylinder, I, where further expansion takes place. Thence it passes to the condenser, J, where it is condensed by salt water from a rose jet. K is the air-pump, and L the outboard delivery-pipe.

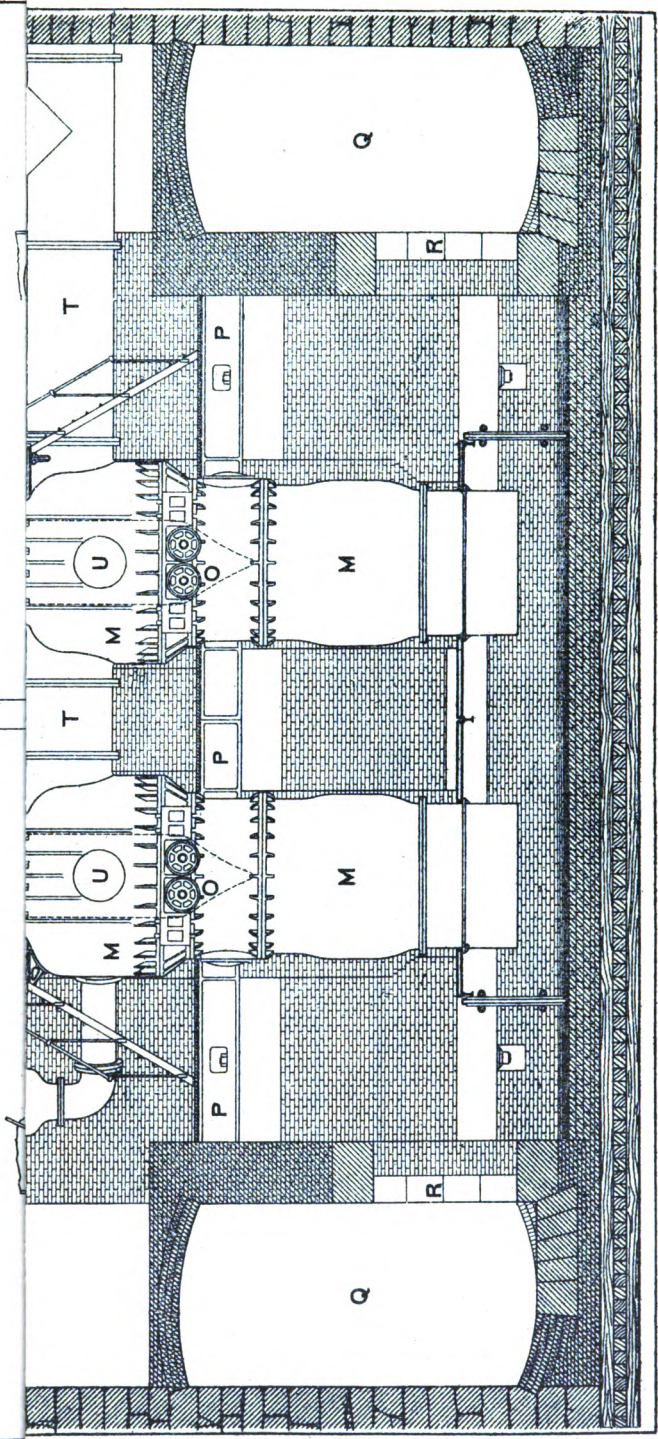
The pumps, M, are hung to heavy girders supporting the engines by cast-iron hangers, N. A part or the whole of the weight of the pumps can also be supported by the wheels, O, resting on very strong cast-iron beams, P, built into the masonry on either side of the pump-wells. By disconnecting their hangers, the pumps, supported entirely by these wheels, can be run back on the beams (which then serve as tracks), and can be hoisted out of the pump-wells without interfering with the fixed parts of the engine.

At Q are side galleries, through either of which the sewage reaches the gateways, R, leading into the pump-wells. In front of these gateways are iron gates, not shown on the plate, which admit or exclude the sewage. S S are the plungers. U U are man-holes. T is the force-main. The discharge from one pump passes through the delivery-chamber of the other.

The interior construction of the pump is shown by Fig. 1 on Plate XIV., which is a vertical section through the pump under the high-pressure cylinder. The plunger is represented as just completing its down stroke. The suction-valves (of which there are 36 to each pump) are closed, and the delivery-valves (27 in number) are wide open, to permit the discharge of the sewage displaced by the plunger. In the other pump, at the same moment, the plunger would be completing its upward stroke, and the action of the valves would be reversed.

The valves are of somewhat novel construction, and are shown by a section of a portion of one of the valve-plates and the whole of one valve (Plate XIV., Fig. 2). As will be seen, they are simply rubber flaps, $\frac{3}{4}$ -inch thick, with wrought-iron

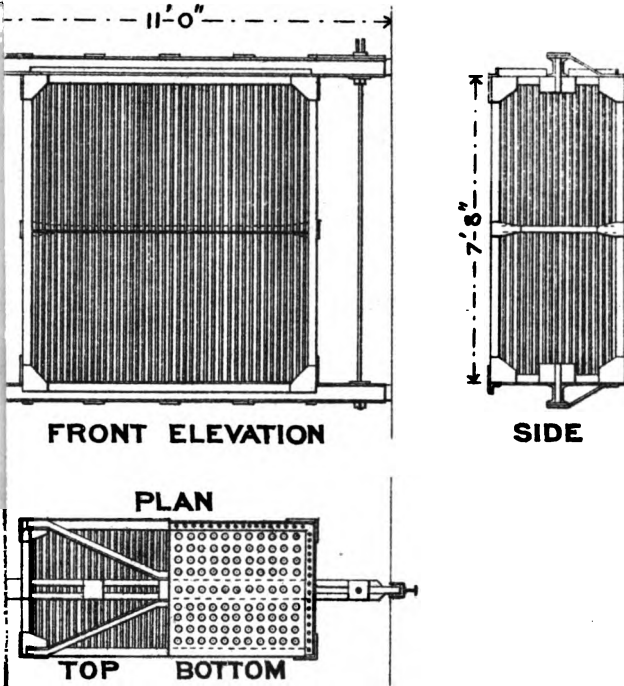
BOSTON MAIN DRAINAGE,
LEAVITT PUMPING-ENGINE.



RELATIVE PRINTING CO. BOSTON



CITY OF BOSTON
MAIN DRAIN
PUMPS AND FILTERS



FILTH CAGES

Fig. 4

CITY OF BOSTON,
 MAIN DRAINAGE.
 PUMPS AND FILTH CAGES.

backs and washer plates, the rubber faces bearing on cast-iron seats inclined at an angle of 45° . The valves form their own hinges, and open against guards or stops faced with leather. The clear opening is $4\frac{1}{2} \times 13\frac{1}{2}$ inches. Pieces of board 10 inches wide and 24 inches long have passed through these valves.

The ordinary working duty of these engines is nearly or quite 100,000,000 foot-pounds to each 100 pounds of coal.¹

The two pumping-engines for storm service were built at the Hydraulic Works, Brooklyn, L.I., by the firm of Henry R. Worthington, of New York, from their own designs, and cost \$45,000 each.

They are of the Worthington duplex, compound, condensing type. Each machine consists in reality of two distinct compound engines coupled together, each engine working a double-acting plunger-pump. The capacity of each double engine is 25,000,000 gallons of sewage a day raised against a total head of 43 feet. This requires about twelve double strokes a minute and a piston speed of about 115 feet per minute.

Steam at from 40 to 50 pounds is carried full pressure through the stroke of each high-pressure cylinder. Thence it passes through reheaters to the adjoining low-pressure or expansion cylinders, and is expanded during the reverse stroke. It is then admitted to the condenser and condensed by a jet of salt water. The steam cylinders are 21 and 36 inches in diameter respectively. They are steam-jacketed all over and suitably coated and lagged. The stroke is four feet.

The steam-valves are moved by a novel and ingenious contrivance, called by the makers "the hydraulic link." Each engine has two small vertical cylinders, in which are plungers worked from the air-pump bell-crank. These plungers force water forward and backward through pipes leading to a cylinder in front of the high-pressure steam-chest. In this

¹ Two duty trials, of 24 hours' duration each, have been made recently of one of the Leavitt pumping-engines. These tests were very carefully conducted, and all fuel burned under the boiler was charged, no deductions being made for ashes and clinkers. In the first trial steam required for the feed-pump was supplied from a separate boiler. Making no deduction for this, the duty developed was a little over 125,000,000 foot-pounds for each 100 pounds of coal. In the second trial the same boiler supplied steam for the pumping-engine and the feed-pump, and the duty developed was about 122,000,000 foot-pounds.

cylinder is a piston connected with the main valve-stem of the engine, and the pressure imparted by the water alternately to opposite sides of the piston, moves the valve-stem and effects the steam distribution.

There are two pumps to each machine. Fig. 3, Plate XIV., is a section through the pumps of one engine. Each pump is double-acting, being divided transversely in the middle by a ring which packs the plunger. The plunger is hollow, 45 inches in diameter, and has a 4-foot stroke. It displaces its bulk of sewage at each stroke in either direction. The positions of the valves, suction and delivery chambers are indicated by the section. The valves are similar to those of the Leavitt engines.

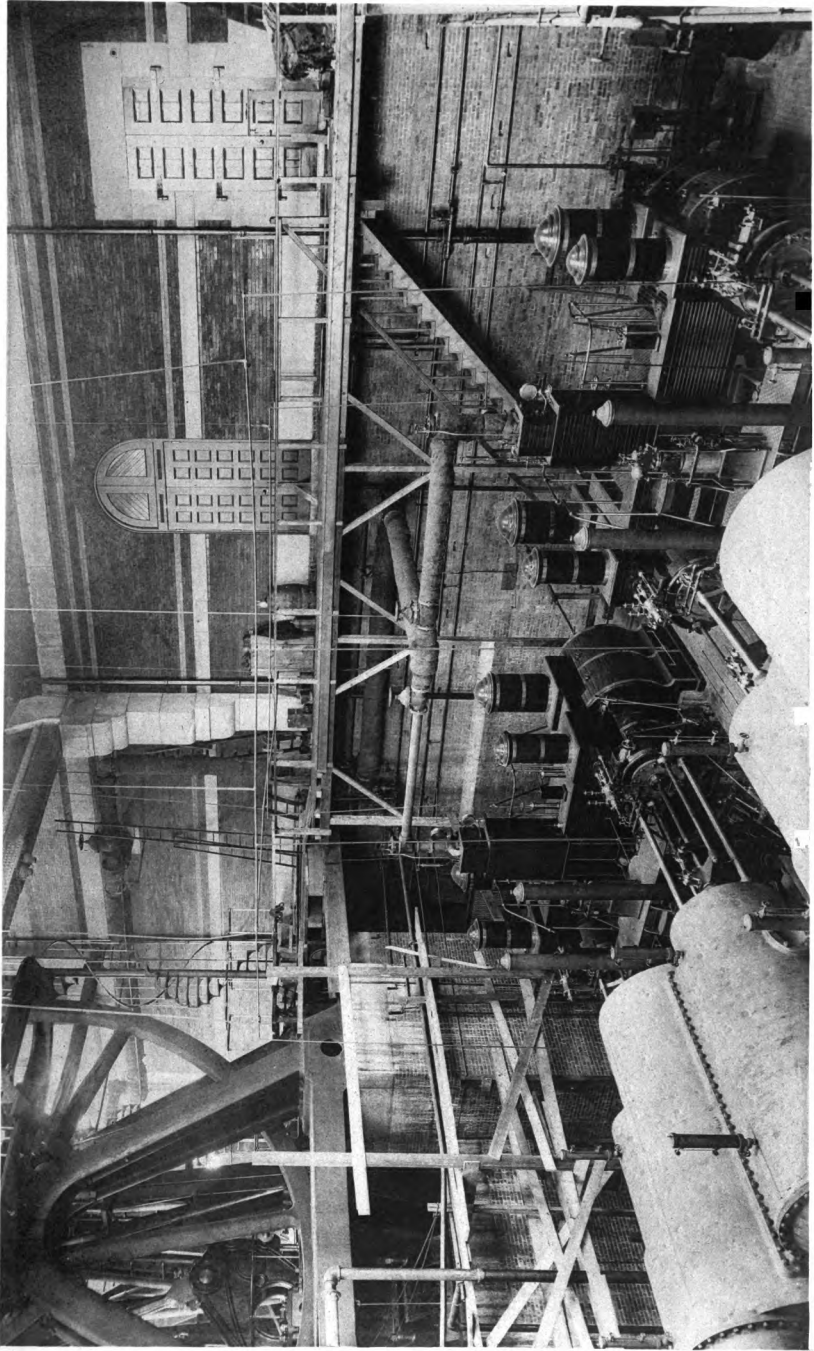
The engines and pumps are compact, and very conveniently arranged for inspection of all their parts. A fair idea of their appearance can be obtained from Plate XV., which is a photograph taken inside the engine-house. The guaranteed duty of these engines is 60,000,000 pounds of sewage raised 1 foot high by the consumption of 100 pounds of coal.

To supply steam for the four engines there are four boilers, of a nominal capacity of 250 horse-power each. They were built by Kendall & Roberts, of Cambridge, Mass., and cost about \$9,500 each.

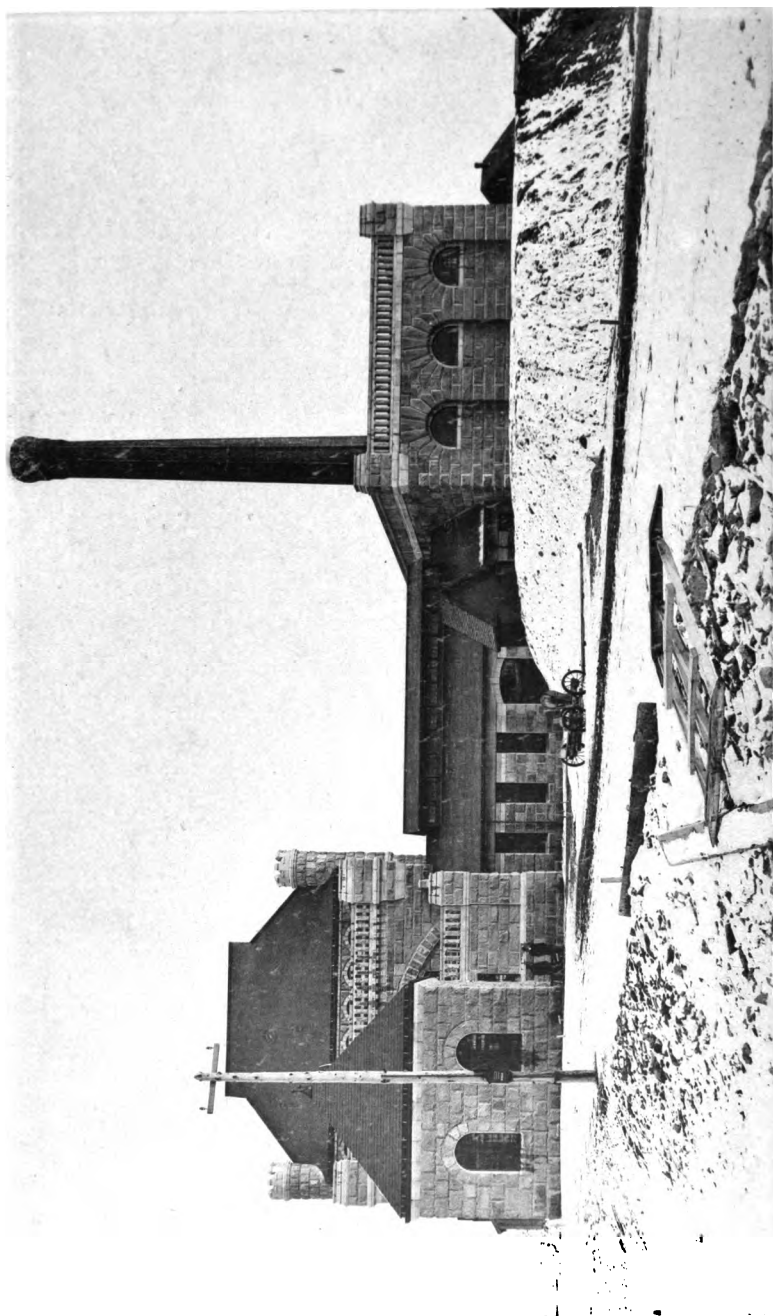
The boilers are of the horizontal fire-box, tubular form, and are made of homogeneous steel, having a tensile strength of not less than 60,000 pounds per square inch, an elastic limit of 37,000 pounds, and an elongation of 30 per cent. The shell is $\frac{7}{8}$ -inch, and the tube-sheets are $\frac{1}{2}$ -inch thick. The length over all is 39 feet 10 inches. There are 132 tubes, 3-inch internal diameter, 15 feet long.

Each boiler has two fire-boxes, $3\frac{1}{2}$ feet wide, 5 feet high, and 11 feet long. At the ends of the fire-boxes is a combustion chamber four feet long.

The smoke-flues return into chambers containing flue-heaters, composed of 80 seamless brass tubes, $2\frac{1}{2}$ inches in diameter and 15 feet long. The heaters are on a level with the boiler-house floor, and can be run out from their chambers for cleaning or repairs. From the heaters the smoke passes by brick flues under the floor to the chimney.



Interior of Engine-House, showing Worthington Pumping Engines.



Main Drainage Pumping Station. Side View.

The chimney has a circular flue, 66 inches internal diameter and 140 feet high.

Among the minor engines and pumps appertaining to the pumping-station are four engines for raising and lowering the filth cages; two engines for moving the gates in the engine-house galleries; two pair of double-acting steam-pumps for feeding the boilers; two double-acting steam-pumps for supplying salt water to the condensers; one large steam-pump for emptying the pump-wells and galleries in the engine-house.

The buildings are warmed by a system of steam-pipes and radiators, and are lighted by gas made on the premises from gasoline.

The coal-house is 129×59.5 feet in internal dimensions. It contains six coal bins, or pockets, with a combined capacity of about 2,500 tons of coal. These bins are 23 feet high, and are built with solid walls formed of 2×6 inch spruce lumber, planed to an even thickness, and spiked flatwise on each other, — a method of construction similar to that used in building grain elevators. The coal-house floor is made of Portland cement concrete. Iron cars are used for bringing coal from the bins to the boilers, and suitable tracks, turn-tables, and scales are provided.

To furnish access to the pumping-station for colliers and other vessels, a channel one-half of a mile long was dredged out to the ship-channel in Dorchester Bay; 380 feet of dock-wall and a wharf 280 feet long were constructed. To facilitate the unloading of coal a coal-run, supported on a trestle 27 feet high, connects the wharf with the coal-house, and extends over the tops of the bins within the house.

Above their foundations all buildings at the pumping-station were designed and built by the City Architect's Department. A front view of the main building is given by Plate XVI (frontispiece), and a side view by Plate XVII. This building cost about \$300,000.

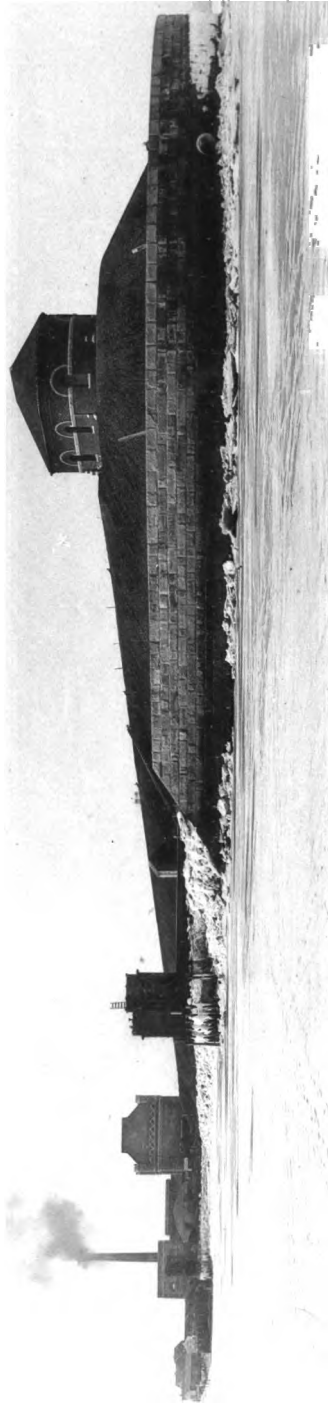
U. S. N. S.

CHAPTER VIII.

OUTFALL SEWER.

THE sewage is pumped through 48-inch iron force mains (Plates X. and XI.) into what is called the pipe-chamber. At this point the sewage reaches its greatest elevation, and is high enough to flow into the reservoir at Moon Island. The pipe-chamber is a granite masonry structure, 51 feet long inside, resting on a foundation bed of concrete, 24 inches thick. The walls are 21 feet high, from 4 to 7.5 feet thick, and contain more than 100 dressed stones. The force mains from the four pumps already provided pass through the westerly wall of the pipe-chamber, and four more short sections of 48-inch pipes are also built into that wall, to connect finally with the four additional pumps, which it is expected may be needed in the future.

From the pipe-chamber the sewage passes into what are called the deposit sewers, and through them flows nearly a quarter of a mile to the west shaft of the tunnel under Dorchester Bay. These sewers are supported and protected by a gravel pier, or embankment, built from the original shore line at the engine-house out to, and including, the tunnel shaft. Plate XVIII. gives a general view of this pier from its outer end. The picture is a reproduction of a photograph taken during the winter when the bay was frozen over. A cross-section of this pier is shown by Fig. 5, Plate XIX. It is built of gravel, which was mostly dredged from the harbor. On its northerly or most exposed side the pier is protected by a rip-rap embankment, ballasted with broken stones and oyster-shells. The southerly slope is ballasted and paved with stone, and the easterly end of the pier is protected by a retaining-wall (Fig. 4) of cut-stone masonry, laid in mortar and backed with concrete, the whole resting on a pile foundation. In all there were used in building this pier about 41,000 tons



View of Old Harbor Pier and Pumping Station, in Winter.

of rip-rap, 16,000 yards of ballast, 120,000 yards of gravel, 600 yards of dimension stone, and 650 piles. The pier was built by contract, and its total cost, excluding that of the sewer, was \$142,064.97.

The general character of the deposit sewers is shown by Fig. 7. As will be seen they consist of a monolithic structure of concrete, forming two conduits, each 16 feet high and 8 feet wide. This height is necessary to accommodate the daily variations in the elevations of the surface of the sewage due to filling and emptying of the reservoir at Moon Island. The sewers are dammed at their lower ends to maintain a depth of from 8 to 10 feet, in order that the velocity of flow through them may be very sluggish, so that any suspended matters may be deposited here before reaching the tunnel. They are provided with gates and grooves for stop-planks, so that the sewage can be turned through either or both sewers, and either can be entirely emptied if necessary.

The whole structure contains about 10 cubic yards of concrete to the lineal foot, or over 12,000 yards in all. The bottom portion up to the straight walls is formed of Rosendale cement, sand, and stone, in the proportion of each, respectively, of 1, 2 and 5. Above this elevation, for the outer side walls, the same proportion is maintained; but the cement used was a mixture of 1 part Portland and 2 parts Rosendale. For the concrete forming the centre wall and top arches only Portland cement was used. The best Rosendale and very fine ground Portland cement were procured for the work. The sand was screened on the spot from the gravel forming the pier, and a portion of the stone was obtained in a like manner. A still larger proportion of the stone came from the tunnel excavation, being brought in lighters from the middle shaft and passed through a stone-crusher. Machine concrete mixers were used, into which the cement, sand, and stones, in proper proportions, were continuously shovelled.

The concrete was rammed thoroughly in 6-inch courses. Long sticks of timber were embedded in each layer of concrete while it was being rammed into place, and were removed after it had set, and before the next layer was added. The spaces

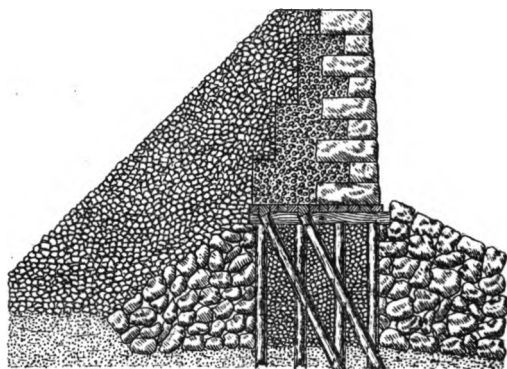
occupied by the sticks formed grooves, into which the succeeding layers bonded. In cutting through one side of this structure six months after its completion the whole mass was found to be perfectly homogeneous, and lines of demarcation between the different layers could not be detected.

The bottoms of the sewers are lined with one layer of hard-burned bricks to resist erosion when the sewers are cleaned. The sides are plastered with a $\frac{1}{2}$ -inch coat of Portland cement mortar. The arches are of long radius and but 13 inches thick. As they were to be loaded at once, they were tied, as shown, by $1\frac{1}{2}$ -inch wrought-iron rods, spaced five feet apart. Brick man-holes were built at intervals of 300 feet.

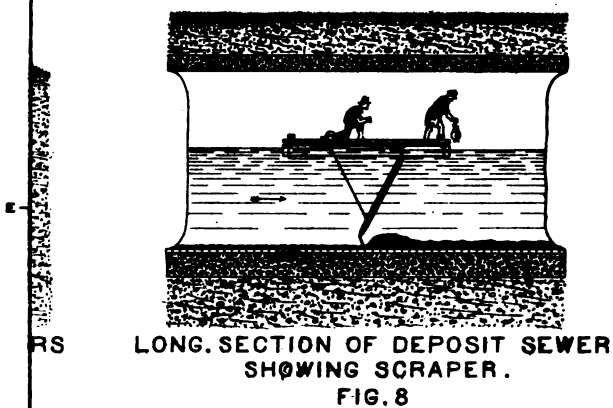
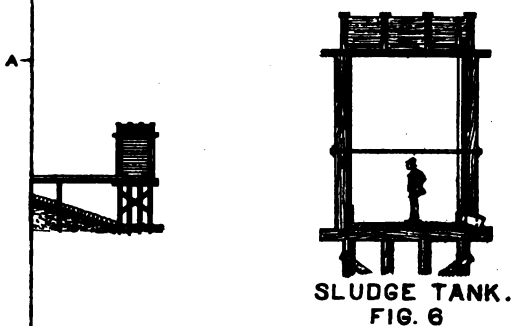
Comparatively heavy matters, such as gravel and sand, settle almost at once at the west end of the deposit sewers. Lighter matters travel a little further; but only a very light semi-fluid precipitate is ever found at the easterly end of the sewers, near the shaft.

The best way to clean out this deposit was long considered, and the following plan was finally adopted. A large wooden tank was built near the end of the pier, just outside of its southerly slope, about 120 feet distant from the sewers (Figs. 3, 5, and 6, Plate XIX.). It is supported on piles, its floor being three feet above high water and one foot lower than the bottoms of the sewers. One end of this tank is connected with the deposit sewers by two 6-inch iron pipes, the other end is connected with the chamber about the tunnel-shaft by a 12-inch pipe. By means of stop-planks the surface of water is made to stand about three feet higher in the deposit sewers than it does in the shaft-chamber. Circulation is thus established from the deposit sewers through the 6-inch pipes into the tank, and thence through the 12-inch pipe to the shaft, and a part of the sewage goes to the tunnel through this by-pass.

The 6-inch pipes leave the deposit sewers near their bottoms, and the sewage which enters the pipes draws sludge along with it and again deposits it in the still water of the tank. The tank is 10 feet wide, 15 feet high, and 50 feet long, and will hold about 150 yards of sludge. It has on its seaward side three gate-openings, terminating in cast-iron nozzles, 12 inches



END WALL OF PIER.
FIG. 4



in diameter. When the tank is full of sludge a scow is laid alongside it, and the nozzles are connected with the interior of the scow by means of canvas tubes. The gates are then opened, and the sludge flows from the tank into the scow.

In order to draw down to the 6-inch pipes the sludge which has been deposited at the upper ends of the deposit sewers scrapers are used. These consist of floating rafts (Figs. 7 and 8, Plate XIX.), made of 12-inch hollow iron tubes, to the bottoms of which are hung wooden aprons, a little less wide than the sewers. The aprons are weighted so that their lower edges, which are provided with broad iron teeth, sink somewhat into the sludge. The current in the sewers carries the whole apparatus down stream, and the sludge is scraped and flushed before it.

The deposit sewers connect with the tunnel shaft at a masonry chamber built about the latter (Figs. 1 and 2, Plate XIX.). At the ends of the sewers are placed gates 7 × 8 feet in size. These gates maintain a depth of eight or more feet in the sewers. They are so arranged that on tripping a latch they can swing open and empty suddenly the liquid contents of the sewers into the tunnel, producing temporarily a strong flushing velocity. Immediately about the shaft is a wrought-iron cage, to prevent any bulky object which may fall into the sewers from reaching the tunnel.

The shaft chamber is encircled by two 6½-feet "waste sewers," into which the deposit sewers can overflow above waste weirs, or with which they can directly connect instead of discharging into the tunnel. The waste sewers unite just east of the shaft-chamber and pass to an outlet built through the sea-wall at the end of the pier. Should the tunnel ever be emptied for inspection sewage can temporarily be pumped into Dorchester Bay through this outlet. Above the shaft chamber is a brick gate-house of ornamental design, built by the City Architect.

The second section of outfall sewer comprises the tunnel under Dorchester Bay. Exploratory borings made on the tunnel line during the preliminary survey showed that the surface of bed rock was but little below the bottom of the harbor, from Squantum to about the middle of the bay. From that

point westwardly towards Old Harbor Point the rock dipped rapidly, so that under the pumping-station its surface is 214 feet below the surface of the ground. The surface of the rock is somewhat shaken, and immediately above it is a water-bearing stratum of sand, gravel, and boulders. Above this, clay extends nearly to the harbor bottom, which is composed of a bed of mud of varying thickness.

The clay is of uniform character, and contains occasional veins and pockets of sand. Using reasonable precautions a tunnel could be safely and expeditiously built in it. The pervious stratum over the rock and the demoralized upper portion of the rock itself were not at all favorable for tunnelling operations, and could only have been penetrated with extreme precaution and a considerable chance of failure. The rock itself was well adapted for tunnelling. It consists of a succession of clay-slates and conglomerates, and belongs to the series known as the Roxbury "pudding-stone" beds.

When the trough in which these beds lie was formed they were subjected to great pressures, which crumpled and tilted them, and produced many faults, fissures, and joint planes. The fissures were filled solidly from below, and few shrinkage seams were found sufficiently open for the passage of water from above. The existence of the joint planes, especially in the clay-slates, greatly facilitated the breaking and removal of the rock.

As at first designed, the tunnel was to start from a shaft 100 feet deep at Old Harbor Point and be built in the clay for about 2,100 feet, when it would enter the rock and continue in it to its end, at Squantum. Further consideration of the difficulty and possible danger of passing gradually from soft ground into rock, and of tunnelling for several hundred feet wholly or partly through very wet and loose material, led to locating the west shaft at such a distance from the shore that rock could be reached at a practicable depth and the tunnel could be safely built wholly within it.

The average elevation of the tunnel is 142 feet below low water (Plate XX., Fig. 1). The total length through which the sewage flows is 7,160 feet. Of this distance 149 feet is in

the west shaft, 6,088 feet is nearly horizontal between the west and east shafts, and 923 feet is in the inclined portion leading from the bottom of the east shaft to the end of the tunnel, on Squantum Neck.

To facilitate construction there were three working shafts about 3,000 feet apart.

The tunnel was built under a contract which was drawn with great care. The contractor was first to build, in accordance with plans furnished, three timber bulkheads, or piers, to protect the shafts. Inside of these bulkheads he was to sink iron cylinders, constituting the upper portions of the shafts. These cylinders were paid for by the lineal foot, and the contractor was permitted and required to build as much of the shafts as possible in this way, loading and forcing the iron to the greatest attainable depth. Below the cylinders the shafts could be excavated of any desired size and shape. The tunnel, also, could be excavated of any size, provided that both it and the shafts were finally lined with a 7½ feet diameter circular shell of brick work, 12 inches thick, backed with brick or concrete masonry to the sides of the excavation. Bricks and cement were to be purchased from the city at stipulated prices. The completed tunnel was to be paid for at the proposed price per lineal foot.

Great stress was laid upon the precautions to be adopted to prevent delay and damage arising from an influx of water into the shafts. Appliances to control any such influx were to be kept in readiness, and, should these prove insufficient, the plenum process, or use of compressed air within the shafts, was to be resorted to.

The work was let Oct. 29, 1879, and the contractor at once proceeded with the building of the bulkheads. These were alike, and consisted (Fig. 2, Plate XX.) of wooden boxes 20 feet square inside, formed of large oak piles, driven two feet on centres, capped and braced with hard-pine sticks, and tied diagonally at the corners with 2-inch iron bolts. The boxes were lined inside with 4-inch tongued and grooved sheet-piling, and the spaces between the sheet planks and cylinders were filled with puddled clay. The tops of the bulkheads were eight

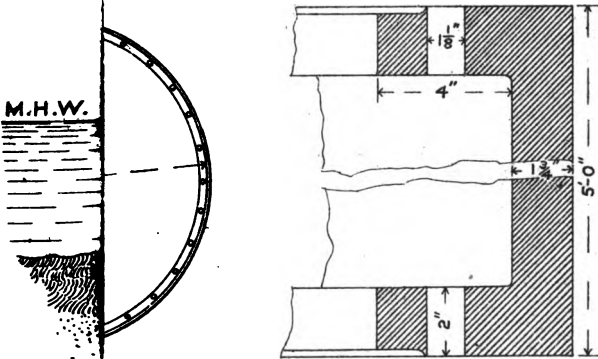
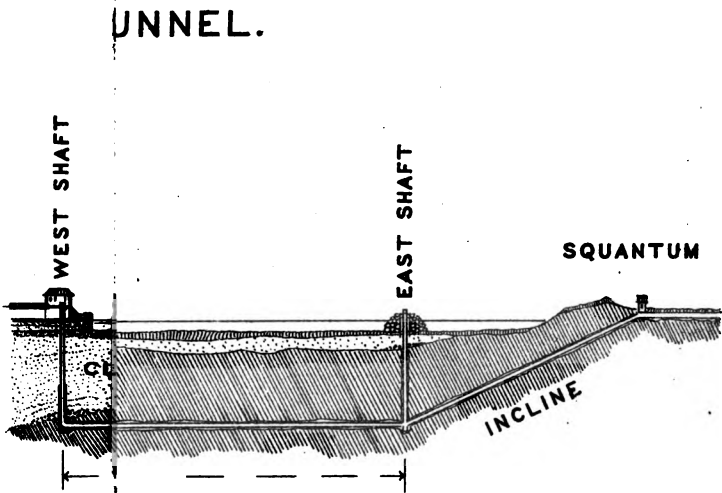
feet above mean high water, and the contract price for them was \$2,500 apiece.

Having completed the bulkheads the cylinders were sunk inside of them. Each cylinder (Plate XX., Fig. 3) consisted of a circular shell of cast iron, 9.5 feet inside diameter, with $1\frac{3}{4}$ inches thickness of metal. They were cast in sections, five feet long, and united by $1\frac{1}{8}$ -inch bolts passing through inside flanges. The abutting ends of the sections were faced, and the bolt-holes, of which there were 30 in each flange, were drilled to a templet, so that the sections were interchangeable. The bottom section of each cylinder had its lower 10 inches chamfered off to a cutting edge. The contract price for furnishing the cylinders, which weighed a ton to the foot, was \$88 per lineal foot.

At the east and middle shafts the cylinders were easily forced down to the rock, at depths below the surface of the ground of 21 and 38 feet respectively. It was known that it would be impossible to drive the cylinder at the west shaft down to the rock. By weighting it with about 180 tons of iron dross it was finally forced into the clay to a depth of about 60 feet below the harbor bottom. Below this point a square shaft, 10 feet across, was excavated with great ease in plastic clay, penetrated with occasional veins of fine sand, but yielding little water (Plate XXI., Fig. 1).

The timbering of this shaft was hastily and, as it seemed to the engineers, carelessly done, the timbers being insecurely braced, and cavities being continually left outside of them. The engineer in charge consulted the City Engineer as to the possibility of requiring greater caution in doing this work. It was decided, however, that the spirit of the contract would not permit interference with the contractor's method of building this portion of the shaft.

No difficulty was encountered until the rock was neared, when water, to the amount of 10,000 gallons an hour, broke in from below, and, no provision having been made for its removal, filled the shaft. Pumps were obtained and the shaft emptied, when it was found that the water, following the cavities behind the lining, had softened the clay and loosened the timbering, so that



SECTION

IRON CYLINDERS

FIG. 3.

it was in very bad shape. About 40 feet in length of the shaft had to be retimbered, the old sticks being cut out with chisels.

This work was not accomplished without great difficulty. Although the quantity of water to be dealt with was not great, the cramped dimensions of the shaft afforded little room for the pumps, or opportunity for supporting them. When these gave out, as they occasionally did, the shaft filled with water, causing considerable delay and damage. To counteract a downward pressure exerted by the clay upon the timber lining, a portion of it was suspended by heavy wire cables from the cylinder above. During all these operations the whole shaft, including timbered portion and cylinder, also the surrounding clay and the bulkhead above, were in motion, settling slowly. By the time the shaft had been firmly founded on the rock the pile bulkhead had settled nearly five feet.

After the shafts had been sunk and secured the excavation for the tunnel proper encountered no serious obstacles. The work was carried on at six different headings. From the middle and east shafts work progressed in both directions, and from the west shaft and the upper end of the incline at Squantum single headings were driven.

The incline descends one foot vertical in six feet horizontal. At this point a heading was driven downwards for about 400 feet and then stopped, owing to the difficulty and expense of removing the water which accumulated at its face. At the middle shaft power drills, driven by compressed air, were used, and at other points hand drilling was employed.

There was not much difference as to either expense or rapidity in the two methods. By either an advance of four feet was considered a fair day's work. The chief merit of the air drills seemed to be that they were not demoralized by pay-days, and never struck for higher wages.

Various forms of nitro-glycerine were employed as explosives, and no casualty occurred through its use. The average diameter of the excavation (Plate XXI., Fig. 2) was about 10.2 feet, approximating very well to the 9.5 feet required to receive the final brick lining. The excavated material, amounting to about 25,000 yards in all, was deposited around the shafts,

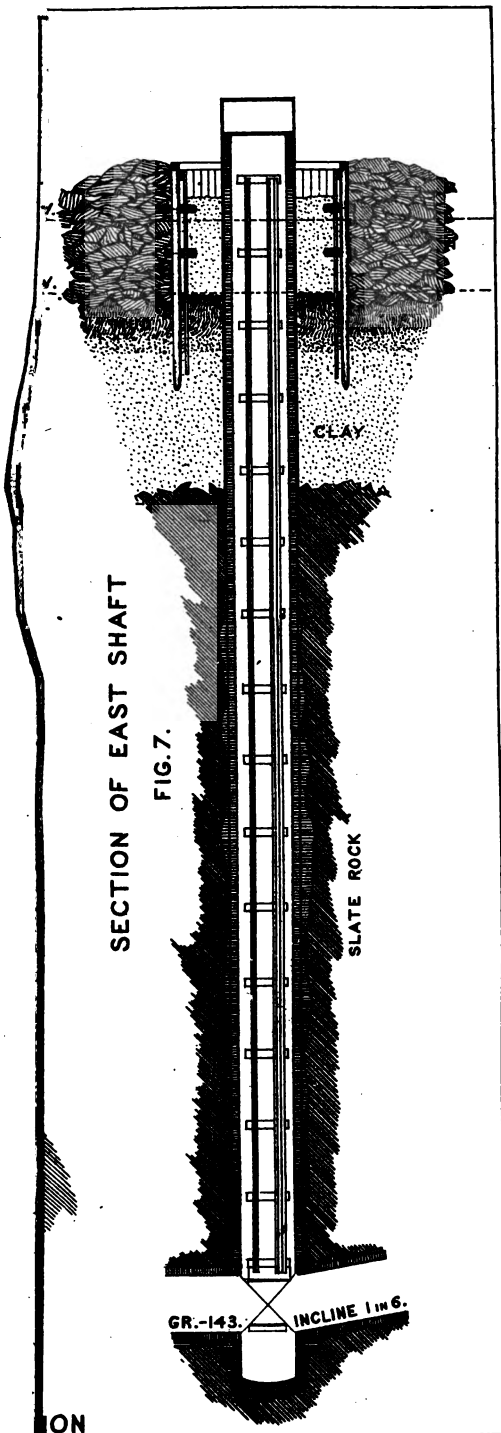
forming small islands. The maximum amount of water leaking into the tunnel at any time was 64,000 gallons an hour.

The headings between the east and middle shafts met Jan. 24, 1882, and those between the middle and west shafts met June 22, 1882. Lining the excavation with brick-work began March 10, of the same year. Projecting portions of rock were first trimmed off, so that room for a solid brick lining, 12 inches thick, laid in courses, could always be obtained. Rosendale cement mortar was used, composed of equal parts of cement and sand. All spaces between the coursed lining and the sides of the rock excavation were solidly filled with masonry, principally brick-work. The amount of backing thus required to make solid work averaged about three-fourths of a yard per lineal foot. Fig. 5, Plate XXI. is a section of the tunnel at the point of maximum size where the largest amount of backing was needed. In all, 7,416,000 bricks and 23,377 barrels of cement were used in building the tunnel. About 12 lineal feet of tunnel could be completely lined in 24 hours, at any one point.

In putting in the lining, iron pipes were built into the brick-work (Plate XXI., Fig. 3) wherever necessary to furnish outlets for the water, which would otherwise have washed out the mortar. Some of these pipes were afterwards plugged, but most of them were left open. The pressure of the water when kept from entering the tunnel was about 64 pounds per square inch, and it was not practicable to build brick masonry which should be water-tight under such a pressure. When the tunnel is in use the pressure of the sewage within it is somewhat greater than that of the water outside the lining, so that leakage would be outwards, except that the particles in the sewage will quickly clog any fine holes in the masonry.

Some experiments were made to determine to what extent the porosity of the brick lining could be destroyed by silting from without. An iron pipe extending up the east shaft was connected at its lower end with the pipes built through the brick-work, and water containing clay, cement, and fine sawdust was forced outside the lining.

The finer portions of these materials came through holes and cracks in the joints of the masonry. Fine holes were thus filled



and leakage through them prevented. Holes of apparent size were calked with lead. By these means the leakage into the inclined portion of the tunnel was reduced from 2,200 to 500 gallons an hour. It was not, however, considered practicable, except at considerable expense, thus materially to reduce the leakage; and, in view of its slight importance in respect to the use of the tunnel, the attempt was given up.

The west shaft was lined with brick-work. The middle shaft was abandoned, its only purpose having been to facilitate construction. The arch of the tunnel where it passes under this shaft was made three feet thick, and a counter arch, two feet thick, was built over it to resist upward pressure, in case the tunnel should ever be filled suddenly after having been pumped out for any purpose. The shaft itself was not filled up, but near its top an arch was built to prevent any heavy substance ever falling down it (Plate XXI., Fig. 4).

The east shaft was lined throughout. A large Cornish mining pump has been purchased, and is to be set up at this shaft as soon as certain legal complications affecting the city's right to the location shall have been settled. This pump will have sufficient capacity to empty the tunnel, including the leakage into it, within 48 hours. It is to be set up as a precaution, as it did not seem wise to leave any portion of the work entirely inaccessible. Should the tunnel ever be pumped out at this point it would first be filled with salt water, so that no possible nuisance could be created by the operation.

A sump, or well-hole, seven feet deep, from which to pump, was built under the east shaft (Plate XXI., Figs. 6 and 7). Pairs of cast-iron beams were built into the lining from the bottom of the shaft to its top. To these are bolted two sets of upright iron guides. One set of these will hold in place the rising column of the pump, and the other set will serve for an elevator, to be used in visiting the pump and tunnel.

It was thought that should deposits occur in the tunnel, they might be removed by passing a ball, somewhat smaller in diameter than the tunnel, through it. To guide this ball past the east shaft, four wooden guides, suitably shaped, were built in place

at that point. Appliances for handling such a ball were provided at the two ends of the tunnel.

The tunnel was practically finished July 25, 1883. Its completion required the removal of all elevators, pumps, pipes, etc., used in constructing it and the closing up with masonry of all pump-wells, except the one before referred to, at the east shaft. This work was attended with considerable anxiety, as the pumping capacity of the three shafts was but little more than was necessary to control the leakage of water.

The finishing and removals were successfully accomplished by systematic and careful management. The last shaft to be cleared was the east shaft, and it was necessary to isolate it from the rest of the tunnel by a timber bulkhead, behind which the water entering the tunnel accumulated while the pumps and their appurtenances were being removed. By the time the shaft was clear the tunnel was two-thirds full of water. The bulkhead was so made and fastened in place that on tripping a catch it fell apart into three pieces, which were hauled out by ropes attached to them.

The contract price for the shafts, exclusive of iron, was \$86, and for the tunnel \$48, per lineal foot. The contractor lost money, and after about two years abandoned his contract, alleging his inability to complete it for the prices therein stipulated. He offered to complete the tunnel for prices about one-half greater than those before agreed upon. Considering that he had the requisite plant on hand, and had acquired valuable experience concerning the character of the work and the best methods of conducting it; and also considering that the bad reputation which the tunnel would have, if abandoned, would probably deter other bidders from making reasonable offers, — it was thought for the best interests of the city to make a second agreement with the same contractor, which was accordingly done. The final total cost of this section of work, including inspection and all incidental expenses, was \$658,489.97, amounting to about \$92 per lineal foot of tunnel.

The methods of alignment employed by the engineers in immediate charge of the tunnel, while not entirely novel, may be of sufficient interest to be mentioned. The west shaft was

out of plumb, so that by dropping plumb-lines a base only 5.7 feet long could be obtained. This by itself would have made accurate alignments tedious. Moreover, each shaft contained about six lines of steam, water, and exhaust pipes, besides guides for its cage. As the shafts were 160 feet deep, were dripping with water, and had currents of air produced by hot pipes and leakages of steam, it would have been necessary to protect plumb-lines by tubes for the whole depth of the shafts. At the west shaft it would have been impracticable to use such tubes, as they would have been directly in the way of the cage.

On account of the difficulty attending the use of plumb-bobs, the line was transferred below by means of a large transit instrument set up at the top of the shaft. The telescope, having been set on line, was directed down the shaft, and a fine string, extending about 100 feet into the tunnel, was ranged in line. The string was illuminated by light reflected from a mirror placed beneath it. Communication between the engineers at the top and at the bottom of the shaft was maintained by the use of hand telephones.

At first the line within the tunnel was produced by means of instruments; but, as the headings advanced, the ventilation became so bad that at times a light distant only 75 feet could not be seen. The line was then produced by stretching a stout linen thread, about 600 feet long, and taking offsets to it. The success attending these methods of alignment was very gratifying, as the headings met without appreciable error.

Should a "high-level" intercepting sewer ever be built to conduct a part of the city's sewage, by gravitation, to Moon Island, it is expected that it will join the present system, on Squantum Neck, at the further end of the tunnel. To provide for such a contingency the present outfall sewer is much increased in size beyond this point, being 11×12 feet in dimensions.

The connection between the tunnel and the outfall sewer beyond is made in an underground chamber (Fig. 1, Plate XXII.). From this chamber, also, branches a short section of sewer with which to connect the future "high-level" system, should it ever be built. The chamber is covered by a substan-

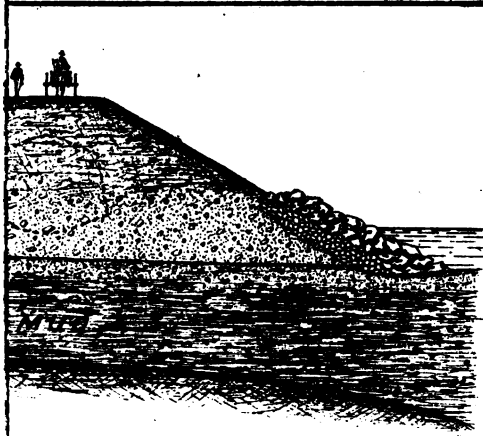
tial brick building, and a flight of stone steps leads to a landing in the sewer below. The floor of the building is supported on iron beams, and can be taken up so that boats can be lowered into the sewer, and a flushing-ball can be taken out. To facilitate these operations the roof was made exceptionally strong, and from it was hung an iron track supporting a traveller and blocks capable of lifting five tons.

As far as the easterly shore of Squantum Neck the outfall sewer (Figs. 4, 6 and 7, Plate XXII.) was built partly in rock excavation and partly in embankment. In the latter case the sewer is tied through its arch by $1\frac{1}{4}$ -inch iron rods, 8 feet apart. These are designed to prevent the possibility of distortion, due to movements of the bank below the sewer, or on the side of it. The ties will, doubtless, rust out in time, but not before the need of them is over.

From Squantum to Moon Island an embankment (Plate XXII., Fig. 5) was built. It is a mile long, from 20 to 30 feet high, 20 feet wide on top, and about 120 feet at its base. Up to the established sewer grade the embankment was chiefly built of dredged gravel, and, above that height, of material obtained in excavating for the reservoir on Moon Island. Up to six feet above high water the slopes are protected by ballast and rip-rap. In all, about 141,000 yards of dredged gravel, 260,000 yards of other earth, 20,000 yards of ballast, and 54,000 tons of rip-rap were used in building the embankment.

About 4,100 feet in length of the site of the embankment consisted of beds of mud, from 10 to 40 feet deep. It was hoped that the filling would displace this mud and reach hard bottom. It did so at a few points, but not as a rule. As an experiment an attempt was made to assist this action by exploding dynamite cartridges under the embankment. No results of importance were thus obtained; but the experiment demonstrated the resistance of the mud to displacement and the probable future stability of the embankment.

Broad plates, with vertical iron rods fastened to them, were placed near the bottom of the bank on its centre line, and the amount of settlement as filling progressed was noted. After the bank was completed slight settlements still continued. It



N SQUANTUM AND MOON ISLAND

Fig.5

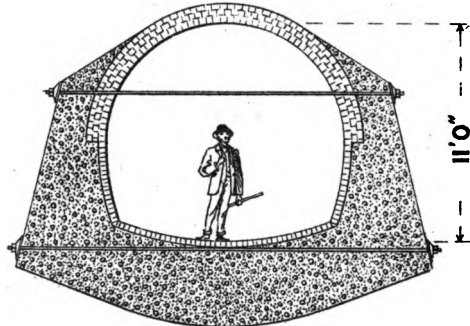


Fig.6

SECTION IN EMBANKMENT.

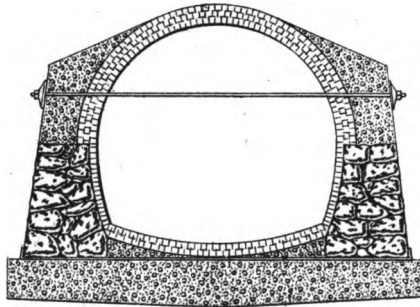


Fig.7

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was, therefore, thought more prudent to postpone building a masonry structure for some years, or until there was assurance that the bank had assumed a condition of permanent stability.

For temporary use therefore, a wooden flume (Fig. 2, Plate XXII.) was substituted for the masonry sewer at this point. The flume is located outside of the embankment, and 200 feet south of it. It is supported on piles, in bents ten feet apart, generally with three piles to the bent. In all, about 1,300 piles were driven, some of them to a depth of 40 feet.

The flume proper consists of a square wooden box, six feet in diameter. Its sides, top, and bottom are formed of Canadian white pine, three inches thick, planed all over. The planks, except a single filling in course on each side, are all of even width, so as to allow breaking joint. They are grooved on each edge, and also on their ends (Fig. 3), for $1\frac{1}{2} \times \frac{3}{4}$ -inch tongues. The box is surrounded, at intervals of three feet four inches, by square frames of spruce timber, mortised together and tightened with bolts and wedges.

The pine and spruce were fitted at the mills, so as to go together with the least possible further fitting. As much as 250 feet in length was assembled and spiked in a single day. After completion the whole was given two coats of cheap paint. The total cost of the flume was a little under \$10 per lineal foot.

From the further end of the flume the outfall sewer (Fig. 6) extends up to and in front of the storage reservoir.

CHAPTER IX.

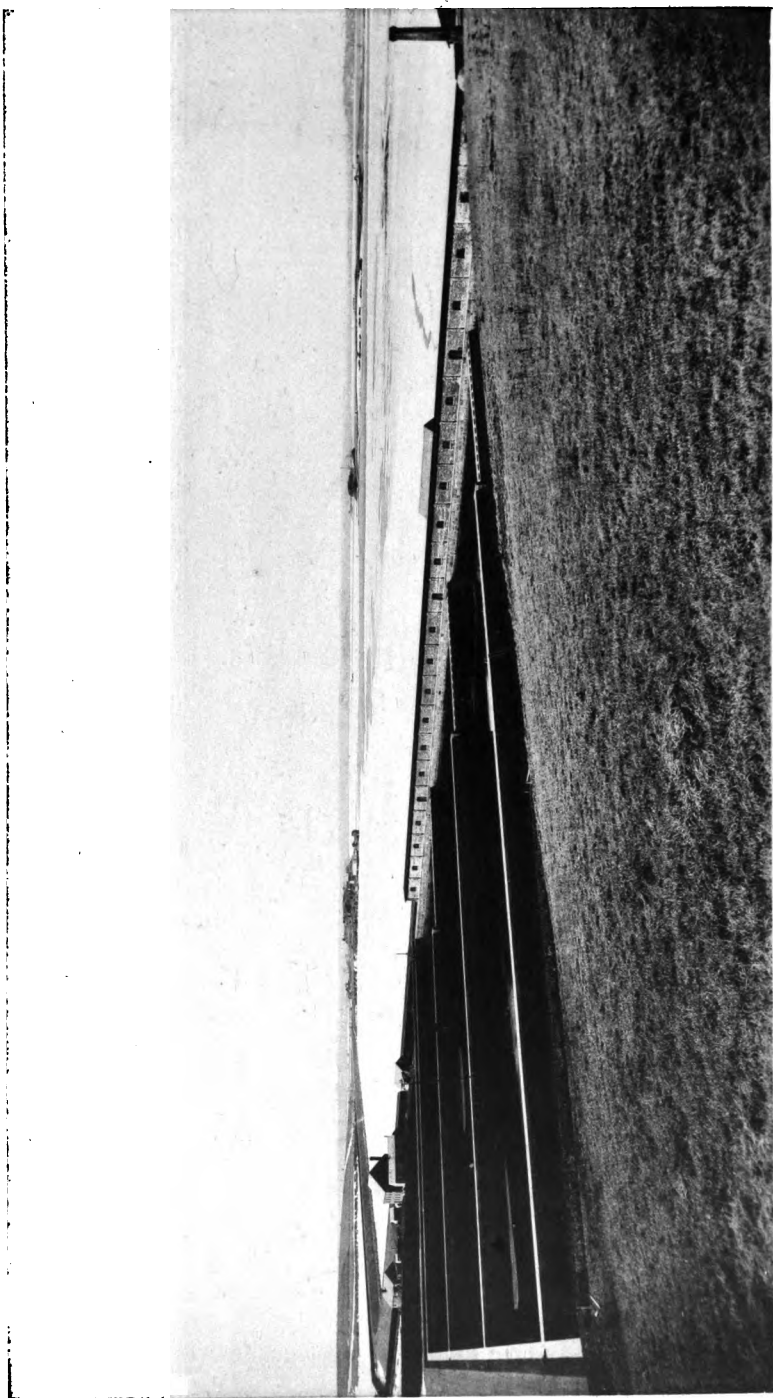
RESERVOIR AND OUTLET.

MOON ISLAND is distant about a mile from the main land. It comprises about 36 acres of upland, surrounded by about 145 acres of beaches and flats. The easterly end of the island rises to an elevation about 100 feet above tide-water. On the western or landward side is another smaller area of rising ground, about 45 feet high. Between these two portions of high land was a valley, crossing the island from north to south, whose central portion was but a few feet above the level of high water. In this comparatively low land the reservoir is situated.

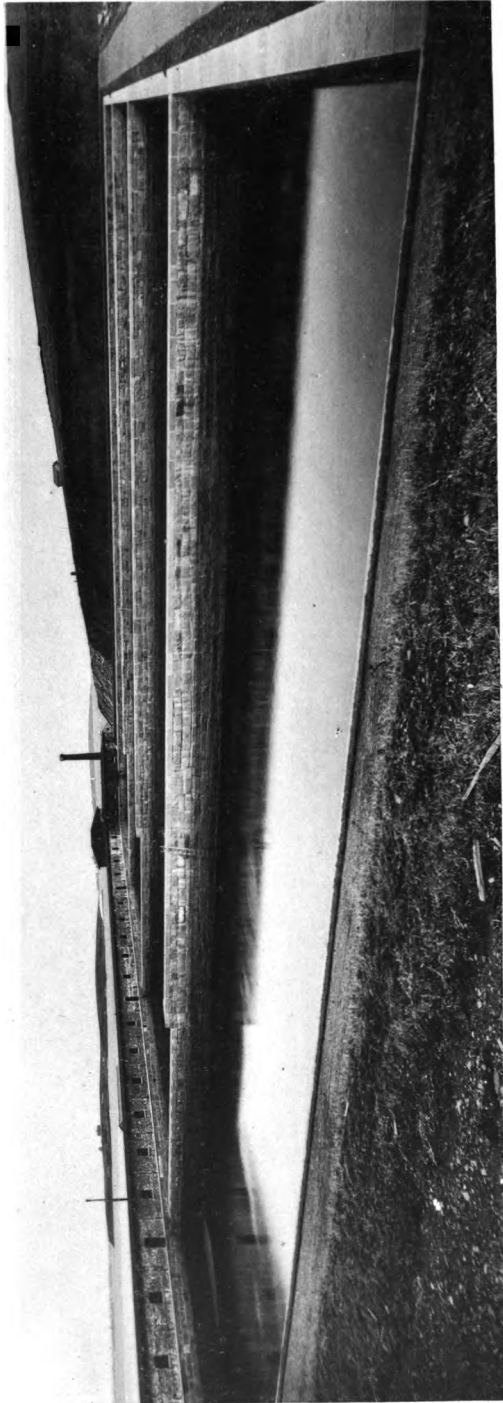
Plates XXIII. and XXIV. give views of the reservoir and its surroundings, reproduced from photographs. The former was taken from the high part of the island just east of the reservoir. It shows the embankment between Moon Island and Squantum, and also the flume, parallel to and south of the embankment. Near the centre of the plate the pumping-station can be dimly discerned, although partly hidden by a clump of trees on Thompson's Island. Plate XXIV. gives a nearer view of the reservoir, looking eastward. It shows one basin partly filled with sewage.

The reservoir, as at present built, covers an area of about five acres. It is expected that in the future, when the amount of sewage to be stored shall have increased, it will be necessary to extend and enlarge the reservoir to about double its present capacity. The portion already built is so located and arranged that the contemplated extension can readily be made on the south side of the present structure.

The site for the reservoir was prepared wholly by excavating. On the centre line of the valley this excavation was about ten feet deep, while on the east and west sides the cutting in places was forty feet deep. A drive-way surrounds the reservoir, and the banks are sloped back from it. The excavated material



View of Reservoir and Outfall Sewer, looking towards City.



Storage Reservoir at Moon Island.

was chiefly hard clay; but a bed of gravel and sand was found near the centre of the valley, which, in places, went 20 feet below the reservoir bottom. Part of the reservoir, therefore, is founded on clay, and another, smaller part on sand and gravel.

The earth was dug by steam excavators, and was carried away in cars by locomotives. It was used for building the upper portion of the embankment between the island and main land. As more earth was needed for this purpose than could be supplied from the reservoir excavation a further quantity was borrowed from the island in such places and to such lines and grades as partly to prepare the site for the proposed future extension of the reservoir. In all, about 283,000 cubic yards of material were taken from the island, and the contractor's price for digging and disposing of it averaged about 59 cents per yard.

The retaining-walls of the reservoir (Fig. 2, Pl. XXVI.) are 17.5 feet high, and from 6 feet 10 inches to 7 feet 10 inches thick at the base. They are classed as rubble-stone masonry laid in mortar, and are built of split and quarry stone mostly brought from granite quarries in Maine. On top of the walls are large coping-stones with pointed surfaces. The rubble stones were laid in somewhat uneven courses. The reservoir is divided into four basins, of nearly equal area by three division walls (Fig. 3), built of the same class of masonry as that forming the retaining-walls. Rosendale cement mortar, made with one part of cement to two of sand, was used in building rubble-stone masonry. The contractor's price for this class of masonry was \$7.47 per cubic yard.

The floor of the reservoir consists of a bed of concrete, nine inches thick (Fig. 6, Plate XXV.). The lower five inches was made with Rosendale cement, sand, and pebbles, in the proportion of one, two, and five parts of each respectively. In the upper four inches of concrete, Portland cement was substituted for Rosendale. The floor of each basin was shaped into alternate ridges and gutters. The gutters are paved with bricks set on edge.

Considering the distance of Moon Island from habitations, it did not seem that any just cause for complaint would be

occasioned if the reservoir were left uncovered, and, therefore, no roof was built over it. But, to provide for any future contingency which might require it to be covered, foundation blocks were built into the floor, on which piers to support a roof can hereafter be built, if needed. These foundation blocks are spaced 20 feet apart in one direction, and 30 feet in the other, and consist of granite stones 3 feet square and 18 inches thick. They are rough-pointed on top and are bedded in concrete. They cost, laid, \$7.25 each.

The reservoir was divided into four distinct basins, in order that one or more of them might be kept empty for cleaning, or some similar purpose, while the others were in use. Under such conditions, however, there might be danger that water from a full basin would find its way down through the thin sheet of concrete under it, and, passing below the division wall, would blow up the floor of an adjacent empty basin. This would be especially apt to occur where the basins and walls are underlaid by the pervious bed of gravel before referred to.

To diminish the liability to such a catastrophe, beneath all walls, not founded on clay, was driven a solid wall of tongued and grooved 4-inch sheet-piling. This protection penetrated the gravel stratum and entered the clay below it. As an additional precaution at such places a line of 10-inch drain-pipe was laid just below the floor on each side of the division wall. These drains were connected with others surrounding the reservoir outside of the retaining-walls. The drains within the reservoir also have 10-inch safety-valves opening into the basins. The drain-pipes were laid with open joints, and were surrounded, below the concrete, with dry-laid ballast and pebbles. Water accumulating beneath the floor of any basin has free access to the drain under that basin. Should any water find its way under a division wall it is immediately intercepted by the line of pipe just beyond the wall. Should a drain under an empty basin become gorged for any reason, the water is discharged into the basin, through the safety-valve, before sufficient head has accumulated to endanger the concrete.

The northerly 100 feet of each division wall, being the end nearest to the discharge sewers, is made hollow, and 1.75 feet



lower than the rest of the reservoir walls (Plate XXV., Fig. 4). Long chambers are thus formed, open on top, but otherwise enclosed within the walls. These chambers connect directly with the discharge sewers, and through them with the harbor. These portions of the division walls serve as waste weirs, by which the sewage in the basins can overflow, if, owing to negligence on the part of the employees, the gates which empty any basin should not be opened before the basin becomes too full.

The arrangements by which the sewage is turned from the outfall sewer into the reservoir and is again permitted to empty, through the discharge sewers, into the harbor, will be understood from an examination of Fig. 1, Plate XXV., which is a transverse section of said sewers. The upper sewer in the figure is a continuation of the outfall sewer, and extends along the whole front of the reservoir. Immediately below it are the discharge sewers, which also extend along the front of the reservoir, and, also, about 600 feet beyond it out into the sea.

In the side of the outfall sewer are 20 3×4 feet, cut-stone gate openings. Only eight of these are at present provided with gates, the others being bricked up until an increased amount of sewage and an extension of the reservoir shall require their use. In the side of the discharge sewer nearest the reservoir are also 20 gate openings, of which 12 are provided with gates. The two discharge sewers are connected directly by 11 large transverse passages. The amount of masonry contained in and surrounding the sewers equals that contained in all of the reservoir walls.

Between the sewers and the reservoirs is what is called the six-foot gallery. This serves as a protection for the gates against frost and as a foundation for a gate-house above. The hollow division walls between the basins extend across the gallery and divide it into four sections, corresponding with the four basins of the reservoir. Brick brace-walls, about 10.5 feet apart, are thrown across from the sewers to the reservoir wall.

The 20 gates, with their frames and seats, are made of cast-iron. The frames were cast in one piece and closely fitted to

the openings prepared in the masonry. They are secured to the stone by $\frac{7}{8}$ -inch anchor-bolts, let in $4\frac{1}{2}$ inches and fastened with brimstone. The seat of each gate is a separate piece of cast-iron, planed $\frac{7}{8}$ -inch thick, fastened to its frame with screw rivets, and scraped true and straight. Fastened to each side of the frame is a guide, which holds the valve in its proper position while moving. The face of the valve is planed and scraped to fit the facing of the frames, so that there shall be no leakage. The valve is pressed tight to its seat by means of adjustable gibs, which bear against inclined planes, cast on the guides.

The gates are moved by lifting-rods and screws, connected with suitable brackets, gearing, and clutches, above the floor of the gate-house (Plate XXV. Fig. 2). A main line of shafting, from $2\frac{1}{2}$ to $3\frac{1}{2}$ inches in diameter, extends the whole length of the gate-house, or about 575 feet. The clutches for each gate are thrown in and out by a hand lever, and also by the gate itself when it reaches either end of its course. The 20 gates, with all their appurtenances and the gearing and shafting for operating them, cost, in place, about \$12,000.

To furnish power both a steam-engine and a turbine wheel are provided. The latter, which is most commonly used, is 21 inches in diameter, and is placed in a well near the north-easterly corner of the reservoir. It takes water either from the reservoir or from the outfall sewer, and drains into the discharge sewers. Under ordinary circumstances it furnishes without expense ample power for moving the gates, running pumps, and other necessary operations, and requires no attention beyond opening and shutting the gates leading to it.

The engine, which is seldom used, is of 30 horse-power. To furnish steam for it and also for heating in winter, there are two upright tubular boilers. The machinery and gates are protected by suitable brick buildings, designed and built by the engineers. The principal one of these, called the Long Gate-House, extends for 575 feet along the front of the reservoir. Connecting with it, at the north-easterly corner of the reservoir, is another larger building, containing engine, boiler, and coal rooms. A chimney, 40 feet high, is also built.



The sewage flows through the gates in the outfall sewer into the six-feet gallery, whence it passes through openings in the reservoir wall into the reservoir. There it accumulates during the latter part of ebb-tide and the whole of the flood-tide. Shortly after the turn of the tide the lower gates are opened, and the sewage flows from the reservoir, through the gallery, into the discharge sewers, which conduct it to the outlet.

That portion of the discharge sewers beyond the reservoir was called the Outlet-Sewer Section, and was built under a separate contract. There are two sewers of brick and concrete masonry (Fig. 1, Plate XXVI.), each 10 feet 10 inches high, by 12 feet wide inside. They extend from the reservoir about 600 feet out into the sea, where there is five feet depth of water at low tide. The bottoms of the sewers are 1.5 feet above the elevation of low water. The arches, 12 inches thick, were laid with Rosendale cement mortar, and the inverts and sides with Portland cement mortar. In the top of each sewer are built three large vent-holes, to relieve the arch from any pressure of air due to a succession of waves entering the sewers.

The immediate outlet consists of a cut granite pier-head laid in mortar. In this are chambers containing grooves for gates and stop-planks. The stones forming the pier-head are quite large, in order to withstand waves and ice. Several of them weighed about eight tons each. Most of the horizontal joints are dowelled, and the vertical joints of the coping-stones are secured by gun-metal cramps.

The sewers are covered by an earth embankment, with its side slopes protected by ballast and rip-rap. This embankment constitutes a pier extending into the harbor, and its top is ballasted and surfaced for a roadway. Near the end of the pier is a strong wharf, about 40 feet square, supported by oak piles. This is used for landing coal and other supplies.

To facilitate construction on this section the site of the work was enclosed by building about 1,100 feet of coffer-dam around it. The dam consisted of two rows of spruce piles, ten feet apart, the piles in each row being spaced six feet on centres. Inside the piles were rows of 4-inch tongued and grooved sheet-piling.

The dam was tied across with iron bolts and was filled with earth. When pumped out it proved to be very tight, and enabled the work inside it to proceed without interruption. After the sewers were built and covered, the dam was cut down below the surface of the embankment slopes. The total cost of this outlet section was \$96,250.

The top of the reservoir floor is about one foot below the elevation of high water. The paved gutters are a little lower, and incline nearly a foot from the back of the reservoir to its front. This insures there being a good current in them when the reservoirs are nearly emptied, so that the light deposit of sludge which has been precipitated upon the bottom of the reservoir is mostly washed into the discharge-sewers.

To assist in cleansing the basins, a system of pipes and hydrants furnishing salt water under pressure is provided. The water is drawn from the sea to a pump in the engine-house, which forces it about the reservoir. A 4-inch pipe, with double hydrants, about 75 feet apart, is laid through the middle of each basin. A line of hose can be connected with any hydrant, and a fire-stream directed against any part of the floor or side walls. The pump can also be used to pump sewage with which to irrigate the banks and grounds surrounding the reservoir.

To obtain fresh water for domestic purposes and for the boilers, the high portion of the island has been encircled with ditches, which collect rain-water and conduct it to a cistern holding 75,000 gallons.

Within the gate-house is provided an automatic recording gauge, moved by clock-work and connected with floats in the sewers. The records traced by this machine furnish a perfect check on the vigilance of the employees. Each day's record shows, by inspection, the hours at which the gates were opened and closed and the height of tide.

The total expenditure by the city on account of Main Drainage Works, from the beginning of the preliminary survey, 1876, to the present time, is about \$5,213,000.

CHAPTER X.

DETAILS OF ENGINEERING AND CONSTRUCTION.

ABOUT one-half of the work required to complete the Main Drainage System was done by contract, and the rest by day's labor, under superintendents appointed by the city. The general rule by which it was decided whether any given section of work should be built by contract, or not, was this: if the work was of such a nature that its extent and character could be determined in advance, so that full and explicit specifications for it could be drawn, it was let out by contract to the lowest responsible bidder. If, on the other hand, all of the conditions liable to affect the work could not be ascertained, so that it was anticipated that modifications in the proposed methods of construction might prove necessary or desirable, the work was done by day's labor.

Thus, wherever in suburban or thinly populated districts the character of the earth to be excavated was supposed to be of uniform quality, most of the sewers there located were built by contract. Those located in crowded thoroughfares, where it was necessary to interfere as little as possible with the use of the street, and those in places where there was liability of encountering deep beds of mud, old walls, wharves, and other obstacles, were built by day's labor.

There was little difference in the quality of the work obtained by these different methods of construction. The contract work was built under more favorable conditions, and as a whole is somewhat superior to the other. It also, as a rule, cost much less. Several reasons can be given for this fact. The physical conditions were generally more favorable. Low prices were obtained through competitive bids. Most of the contractors made no profit; some even lost money. The contract work was largely done during the first few years of construction, when all prices were lower; while the bulk of the work done by day's labor was built later, when prices for labor and

materials had risen. The wages paid city laborers were fixed by the City Council, and were always higher than the market rates. At times the city superintendents were not untrammelled in respect to hiring and discharging their employees.

Sixteen sections of sewer were let by contract. In two cases the contractors failed, and the sections were relet. In four other cases the contractors abandoned their work, which was completed by the city, by day's labor. In connection with the Main Drainage System about 50 more contracts were made for materials and machinery, and for construction and work other than sewer building. These contracts were drawn by the engineers.

In preparing a contract for building a sewer the object kept in view was to describe only the general character of the work, and to leave for further decisions, as construction progressed, the exact shape, methods of construction, and amounts and kinds of materials to be used. That this might be done without unfairness to the contractor the precise character (but not the amount) of every kind of work and material, which might be called for, was specified, and a price was agreed on for each. Should anything not specified be called for, the contractor agreed to furnish it at its actual cost to him, plus 15 per cent. of said cost.

This is a convenient form of contract, because it permits the engineer to modify his methods of construction whenever experience shows that a change is desirable. One kind of material can be substituted for another; cradles, side walls, and piling can be added or discarded. Rather more opportunities for contention are afforded by this form of contract than by a simpler one; but, on the whole, it was considered the best for our purposes.

Contract work was carefully watched, an inspector being continually on the ground. Great care was taken to select suitable men for such positions. They were all experienced masons, and were paid \$4.00 or more a day.

A daily force account was always kept, both of work done by the city and that built by contract. This recorded the number of hours' labor of every class and the amount of material which

entered into each part of the work, so that its cost could be ascertained. On contract work this record proved very useful, because it furnished conclusive evidence in any case of disagreement as to quantities or cost.

All materials were carefully inspected for quality. Especial care was exercised in inspecting bricks and cement. About 50,000,000 of the former and 180,000 casks of the latter material were used in building the works. It was required that the bricks should be uniform in size, regular in shape, tough, and burned very hard entirely through. Bricks with black ends were not excluded if otherwise suitable. No machine-made bricks were accepted, as they were usually found to have a laminated structure. A moderate proportion of bats was allowed, but only in the outer ring of the covering arch. From the accepted bricks the most regular were culled out for inside work. Bricks from different localities varied considerably in size, and this fact, so often disregarded, was taken into account in making purchases for the city. For instance, 1,175 Bangor bricks were required to build as much masonry as could be built with 1,000 Somerville bricks.

A requirement that no bricks should be used which would absorb more than 16 per cent., in volume, of water, although not always enforced, was occasionally found useful, because it permitted the rejection of bricks made of light, sandy stock, which were, however, perfectly hard and shapely. The following was the method employed in testing for porosity. The brick to be tested was first dried thoroughly by artificial heat, and then weighed. Next it was put in a pan containing one-half inch of water and allowed to soak for 24 hours, the pan being gradually filled, by adding water from time to time until the brick was covered. When thoroughly soaked it was again weighed, both in water and in air. The difference between the weights dry and soaked, in air, was the weight of water absorbed, and the difference between the weights of the soaked brick, in air and in water, was the loss of weight in water, i.e., the weight of a bulk of water equal to that of the brick; then $\frac{\text{The weight of water absorbed}}{\text{The loss of weight in water}}$ was the proportion, in volume, of water absorbed by the brick.

Natural "Rosendale" cement was chiefly used on the work, but about 26,000 barrels of Portland cement and a little Roman cement were also used. Portland cement mortar was often used in building the invert of sewers and, in general, where there was liability to abrasion or where especial strength was needed. It was often mixed with Rosendale cement in order to make a somewhat stronger mortar. Very quick-setting Roman cement was used for stopping leaks, and was also mixed with other cements for wet work, because it would set at once and keep the mortar from being washed down before the stronger cements had hardened.

In Appendix A is given a full account of the methods employed for testing cement, and also the results derived from the tests made for experimental purposes. One advantage resulting from the careful and systematic testing was that manufacturers and dealers were themselves careful to offer or send no cement but that which they felt confident would be accepted. During the first year or two much of the cement offered was rejected, but later very little of it proved unacceptable. In making contracts for cement a standard of strength and fineness was seldom given. It was simply stipulated that the cement should be, in every respect, satisfactory to the engineer, and, if not satisfactory, should be rejected.

In one contract, however, for 5,000 barrels of Portland cement, a certain fineness and strength were required. As some of the specifications of this contract are believed to be novel and practically useful, they are here cited : —

Fineness. The cement to be very fine ground, so that not over fifteen (15) per cent. of it will be retained by a certain sieve deposited in the office of the City Engineer of Boston, said sieve having 14,400 meshes to the square inch.

Strength. The cement, when gauged with three parts by measure of sand, to one part of cement; formed into briquettes having a breaking area of $2\frac{1}{4}$ square inches; kept 28 days in water and broken from the water, to have a tensile strength of 150 lbs. per square inch.

Price. We agree to receive as full payment for the satisfactory delivery of said cement, subject to its fulfilment of the foregoing requirements, as determined by the City Engineer of Boston, the sum of three dollars (\$3.00) per cask delivered and accepted.

We further agree, that, shall the cement, or any portion thereof, fail to

fulfil the above-mentioned requirement as to fineness, but shall nevertheless be accepted by the city, we will receive as full payment for said cement, or said portion thereof, a sum to be determined by the City Engineer, by deducting from the full price, of three dollars (\$3.00) per cask, the sum of two cents (\$.02) per cask for each per cent. greater than 15 per cent. that is retained by the sieve before mentioned.

Contractors were required to use only clean, sharp, coarse sand for making mortar. On city work, if clean sand was not conveniently accessible, a moderately dusty or dirty sand was considered almost as good, and quite good enough. So, also, in making concrete, contractors were obliged to use screened sand and stone; but a city superintendent might mix his cement directly with the gravel dug from the bank, if it was more convenient and cheaper to do so. Comparative tests of concrete made by these different methods failed to distinguish any superiority in one over the other.

The city sewers were so low that the intercepting sewers, which had to be lower still, required unusually deep trenches. The average depth of cut for the whole system was more than 21 feet. The bottom of these trenches was generally several feet below the elevation of low tide. As the new sewers followed the margins of the city near the sea, tide-water frequently found access to the trenches, so that construction could only proceed during a few hours at about the time of low tide, when the leakage of water could be controlled. Sometimes the trench could not be kept entirely free from water. Many of the streets traversed by the sewers were underlaid by beds of mud. Generally the mud was not so deep but that an unyielding foundation could be secured by driving piles through the mud down into the hard ground beneath. Sometimes, however, the mud was so deep that hard bottom could not be reached by piling.

It was under such conditions that the use of wood to form the whole, or the lower part, of the sewer was resorted to. Wood was no cheaper in itself than masonry; but a wooden sewer could be built very much more rapidly than a brick one, and could be built by unskilled laborers. Also, a wooden invert could be fastened in place, if necessary, under a foot or two of water. Moreover, a wooden sewer, fastened by spikes

and oak treenails, possessed considerable elasticity, and could settle slightly in places, or assume an undulating form, without breaking.

Therefore, under conditions such as those just mentioned, the use of wood to form the shell of a sewer was often resorted to. There were disadvantages attending this mode of construction. The elasticity which permitted the sewer to bend longitudinally without breaking, also made it tend to yield transversely, sinking at the crown and bulging at the sides, whenever the earth outside was at all compressible. It was not easy to prevent the wooden shell from leaking badly, especially at the end joints. All wooden sewers had to be lined with brickwork, or concrete, to make them smooth and tight; but putting such lining inside of a leaky sewer is a somewhat tedious and difficult operation.

The tops of most of the intercepting sewers are several feet below the level at which ground water stands in the earth about them. Great pains were taken to insure every joint being thoroughly filled with mortar, and the arches were always plastered outside with a half-inch coating of cement mortar. By such means the greater part of the system was made perfectly tight and dry. In places, however, especially where there were slight settlements and cracks, a considerable amount of leakage occurred. All leaky joints were calked as well as possible. Various materials were used for this purpose. Among them were neat cement; cement mixed with grease or with clay; oakum; dry pine wedges, and sheet lead. By one or several of these methods the leakage could either be entirely stopped or reduced to an insignificant amount.

A considerable item in the total cost of building the intercepting system was the expense incurred in repairs to street surfaces and paving, over the sewers. The trenches were so large and deep that the backfilling, often of a peaty consistency, could not be sufficiently compacted by ramming or puddling, but continued to settle for a year or more after the sewer was built. As it was necessary to keep the surface in a safe and reasonably smooth condition the portion over the trench was sometimes repaved three, or even more, times before

it would remain permanently in place. Where the earth underlying the street was of a peaty nature, it would be rendered spongy and compressible by its water draining out into the open trench during construction. Then the whole street surface, including sidewalks and sometimes even adjacent yards, would settle out of shape and need repairing.

Another source of expense and trouble was the breaking of house-drains where they passed across the sewer trench, due to the settlement of the backfilling. The intercepting sewers were frequently, indeed generally, built in streets which already contained a common sewer. The house-drains from one side of the street crossed the trench of the intercepting sewer. These drains were maintained, or replaced, as securely as possible, but many of them were afterwards broken. These were generally found to be sheared off on the line of the sides of the excavation, and the portion within the trench sunk bodily, half a foot or so, below the rest.

As a rule the streets in which sewers were built were kept open for traffic. When the trench was in the middle of the street, passage-ways for vehicles were maintained on both sides of it, even when the width between sidewalk curbs was only 26 feet. This was accomplished by the use of an apparatus for excavating and backfilling, invented by the superintendent, Mr. H. A. Carson, and afterwards patented by him. Various merits are claimed for it, but the chief advantage in its use at Boston was, that by it sewers could be built with very little encroachment on the surface of the street. Views of the apparatus are given on Plate XXVII. Although a patented article, a brief description of it seems proper, since it was used in building more than one-half of the intercepting sewers.

In its general features the apparatus consisted of a light frame structure, extending longitudinally over the sewer trench from a point in advance of where excavation had begun, to another behind where the trench was completely backfilled. All operations, therefore, were carried on beneath the machine. Excavation proceeded under the forward portion of the frame, the sewer was built under the central portion, and backfilling progressed near the rear. A double-drum hoisting

engine was carried on a platform at the front end of the frame. From the top of the frame were suspended iron tracks, on which were travellers, moved backwards and forwards by wire ropes leading to the engine. A number of tubs, loaded by the diggers in front, were hoisted simultaneously by the engine, and run back to be dumped over the completed sewer. They were then returned and lowered to the points whence they had been taken, by which time a second set of tubs had been filled ready for hoisting.

Any surplus earth was dumped through a hopper into carts which were backed under the machine. When it was necessary to furnish a passage across the work the trench was bridged, and the frame trussed. When one section of excavation was completed, the whole apparatus, which rested on wheels, was pulled forward 30 or more feet by its own engine. The average total length of one apparatus was 200 feet, and its total weight about 10 tons.

Sewer building, done by the city, was frequently carried on through the winter months. Contractors, on the other hand, were not allowed to lay masonry between November 15 and April 15. The temperature at the bottom of a deep trench was always considerably higher than that at the surface of the ground; so that it was only when the mercury was at ten or more degrees (F.) below the freezing-point that work was suspended. Much extra precautionary work was needed. Bricks were steamed in a close box before using; sand and water were warmed, and completed work was protected by coverings of straw or sea-weed. Winter work was not economical, and was resorted to chiefly for the purpose of employing laborers, who otherwise might have been idle.

Experience is probably a better guide to designing stable sewers than are theories concerning lines of pressures and geostatic arches. The physical conditions which determine the direction and amount of the earth pressures are seldom the same in the case of any two sewers. They differ at different points about the same sewer, and often are not alike on both sides of one sewer. The best that can be done is to judge as well as possible of the character of the ground to be penetrated, and

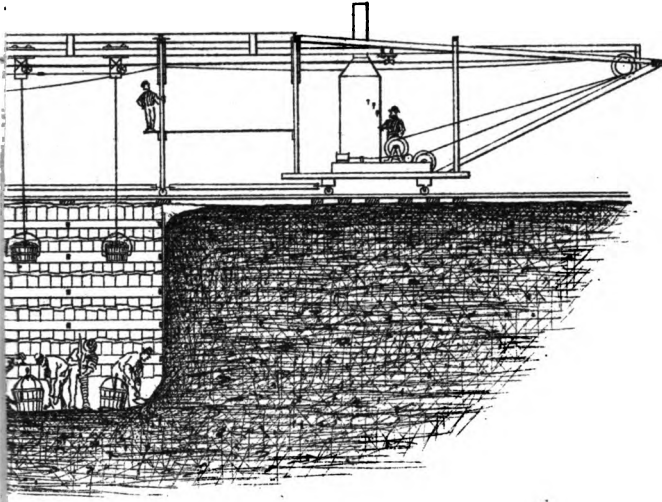


DIAGRAM MACHINE

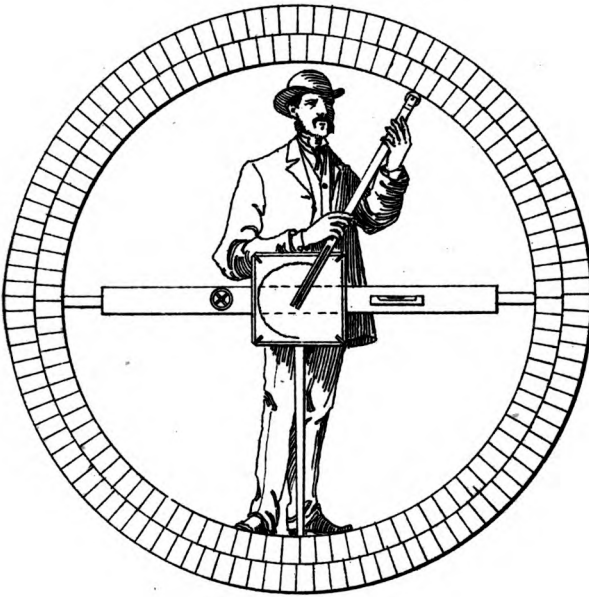


Fig.4

begin to build such a sewer as has proved stable under similar conditions. The sewer should then be examined carefully, during and after loading, for signs of weakness.

In the case of the main drainage sewers such examinations were made graphically, by taking diagrams of their inside shape. These diagrams were taken by the aid of a machine shown on Plate XXVII. It consisted of a light frame, which could be so fixed against the masonry that its centre should be in the axis of the sewer. A movable arm was then rotated radially from the centre, with its outer end bearing lightly against the inside perimeter of the sewer. At the centre of the machine was a disk, on which was placed a sheet of paper. A pencil point, attached to the rotating arm, traced upon the paper a diagram, showing the shape of the sewer and its variation, if any, from the established form.

The shape and amount of any distortion suggested the cause which produced it, and the remedy to be applied. The most common causes were too early removal of centres; too rapid or unequal loading; the use of improper material for backfilling about the sewer; insufficient ramming of backfilling against the haunches; withdrawing sheet planks after backfilling; inherent weakness in the design of the sewer. Such errors could be corrected and the design of the structure could be modified until the diagrams taken from the sewer were found to correspond with its proper shape.

The Main Drainage System is so arranged that any principal portion of it can be isolated and emptied for inspection and repair. Any intercepting sewer can be thus isolated by closing the penstock gate at its lower end, and also the inlet valves connecting it with the common sewers, the latter then discharging at their old outlets. By closing the gates at the ends of all intercepting sewers the main sewer can be emptied. Wherever an opportunity for isolating a small portion of the works might prove desirable, but the use of iron gates for such purpose would have entailed unwarranted expense, as a cheaper substitute, grooves of iron or stone were built into the masonry for stop-planks. Such grooves for stop-planks were always built above any iron gates, to afford a means of access in case

of needed repairs. Where slight leakage could be afforded, a single pair of grooves were considered sufficient. Where a tight dam was desirable, a double set of grooves was provided, so that a double set of stop-planks, with an inside packing of clay, could be used. Some hundreds of stop-planks, of different lengths, are kept in readiness. Their form is shown on Plate XXVII. They are made of hard-pine planks, from three to five inches thick, planed and oiled.

The connections between the common sewers and the intercepting sewers were usually made during the construction of the latter. The valves of the inlet-pipes, built into the common sewers, were closed and made tight by a little cement around their edges. By raising these valves the connection between the old and new system could at any time be established.

CHAPTER XI.

WORKING OF THE NEW SYSTEM.

JANUARY 1, 1884, the connections between the common and intercepting sewers were first opened. Pumping began at the same time, and the sewage was sent to the reservoir at Moon Island, and thence discharged into the Outer Harbor. Connection with about one-half of the common sewers was made on that day, and most of the others were connected within a month thereafter; so that by February, 1884, nearly all of the city sewage was diverted from the old outlets. The upper portion of the West Side intercepting sewer, in Lowell and Causeway Streets, was built in 1884. The common sewers, tributary to it, were intercepted as construction progressed. A common sewer draining a portion of Dorchester, intercepted by the main sewer at East Chester Park just east of the N.Y. & N.E. Railroad, was not connected until early in 1885.

Although the whole intercepting system, therefore, was not entirely completed until the present year, yet the greater part of it has been in operation for fifteen months, — a long enough period to afford a fair indication of its practical working, and of the results which will be derived from it.

As elsewhere stated, the Main Drainage Works were designed and built to correct two principal evils inherent in the old system of sewerage. These were: —

First. The damming up of the common sewers by the tide, by which, for much of the time, they were converted into stagnant cesspools, and the air in them was compressed, and to find outlets was driven into house-drains and other openings.

Second. The discharge of the sewage on the shores of the city in the immediate vicinity of population, thereby causing nuisances at many points.

The first of these evils has been entirely corrected by the new system. The old sewers now have a continual flow in them,

independent of the stage of the tide, as has been ascertained by frequent observations, and also from the testimony of drain-layers, who formerly were only able to enter house-pipes into the the sewers when the latter were empty at low tide, but now can make such connections at any time.

The new system has also substantially remedied the second evil. From the moment that any of the city sewers was connected with an intercepting sewer; the sewage which had before discharged on the shore of the city was diverted, and has since been conveyed to Moon Island and emptied into the Outer Harbor at that point.

It is true that about twenty-four times during the past year, or an average of twice a month, during rain-storms and freshets, the amount of water flowing in the sewers has exceeded the capacity of the pumps. At such times the excess has been discharged at the old sewer outlets. But this occasional and temporary discharge of very dilute sewage does not seem to have occasioned any nuisance. Examinations and inquiries concerning the condition of the shores and docks at the sewer outlets have shown that water, once continually foul, has become pure, bad odors have ceased, and fish have returned to places where none had been seen for years. The stench, referred to by the City Board of Health (p. 13), which formerly, at times, were prevalent over the city, were not noticed during the past year.

The attempt to relieve certain low districts, subject to flooding of cellars during rain-storms at high tide, by discriminating in favor of such districts in respect to the interception of storm-water, has met with marked success. No case of flooding in such districts has been reported since the sewers draining them have been connected with the interceptors; and many cellars, which used often to be filled several feet deep with water, are known to have been perfectly dry during the past year.

Building the intercepting sewers has also dried cellars in other parts of the city in a way which was not at first anticipated. When land on the shores of the city was reclaimed for building purposes, most of the old walls and wharves were covered up by the new filling. Tide-water followed along any such structures through the ground, and entered cellars lower than high-tide

level. The new sewers were generally built along the present margins of the city, and in digging deep trenches for them the old structures found were cut off and removed. The backfilled earth in the trenches forms an impervious dam surrounding the city, beyond which tide-water cannot pass.

The sewers have been examined frequently since they went into operation. The average depth of dry-weather flow in the intercepting sewers is from ten to twenty inches, so that they can be entered on foot. So, also, can the main sewer above Tremont Street, and, sometimes, above Albany Street. Below that point the dry-weather flow is from two to three feet deep, necessitating the use of a boat.

The velocity of flow in the sewers varies from about two feet a second upwards. An attempt was made to measure the velocity at several points with a current meter. While integrating, the meter rarely could be kept under water longer than ten seconds at a time without danger of its being clogged by paper, hair, and similar substances. By the use of a stop-watch the instrument could be removed for cleaning and again immersed without interfering with the experiment. The inclination of the surface of the sewage, though approximately the same as that of the sewer, was seldom precisely the same, and the observations were not sufficiently exact, in any case, to determine just what inclination then existed. The mean velocity at the points of measurement were, however, accurately ascertained, and the results may be of sufficient interest to cite.

In the case of a 4×4.5 feet sewer (Fig. 7, Plate VIII.), with an inclination of 1 in 2,000, flowing 1.23 feet deep, the mean velocity was 1.9 feet per second. This sewer had some gravel on its bottom. In the case of a 4.75×5.5 feet sewer (Fig. 8, Plate VIII.), with an inclination of 1 in 2,000, the depth was 1.45 feet, and the mean velocity was 2.45 feet per second. In a 4.5 feet circular sewer, with an inclination of 1 in 700, and a depth of 1.15 feet, the mean velocity of flow was 2.56 feet per second. In the case of an 8.25 feet circular sewer (Fig. 14, Plate VI.), the inclination being 1 in 2,500 and the depth 1.76 feet, the mean velocity was 2.59 feet per second, sufficient to keep in suspension and carry along all sewage sludge. Most of

the city sewers, when first intercepted, were found to contain deposits of sludge varying from a few inches to several feet in depth. All these deposits were carried into the intercepting sewers, and the sludge reached the pumping-station and was pumped up into the deposit-sewers. Gravel, stones, and brick-bats also were swept along and taken out at the filth-hoist. Fine sand, however, did not move so freely, but settled in ridges here and there, and had to be removed by hand.

The bottoms of the sewers are, as a rule, perfectly clean. No slime accumulates there, or, if it ever begins to grow, it is at once scoured off by the attrition of moving particles. The sides of the invert below the surface of the water have a thin coating of slime, making them very slippery. The arch and the portion of the invert above the water exposed to the air are clean, and often quite dry. In some portions of the sewers earthy accretions form on the arch. Where the sewer is surrounded by marsh mud these are turned black by sulphuretted hydrogen, sometimes they are colored yellow by iron, often they appear as white stalactites. In clayey soil the arch seems to be about as clean as when laid.

The atmosphere in the sewers is not offensive, although a faint sewage smell can be detected on first entering them. For the first eight months after the sewers went into operation they were not ventilated at the man-holes. This was because it was known that much sludge would be turned into them from the common sewers, and it was feared the smell from it might be noticed. Finally the ventilating covers, shown on Plate VI., were put in place. No smell has ever been noticed from them, and they considerably improved the condition of the atmosphere in the sewers, which is now quite fresh and hardly at all disagreeable; not so much so, for instance, as is that in most railway carriages after an hour's use. The temperature of the sewage varies from 50° to 65° F., and that of the air in the sewers from 40° to 60° F., depending upon the outside temperature.

A small force of men has been constantly employed during the past year, in caring for the main and intercepting sewers. This force has consisted of a foreman, one carpenter, and four laborers. They have also done minor items of work and repairs

which might properly be charged to construction. After every rain, whenever there was any likelihood that water might have overflowed at the old outlets, all of the tide-gates have been visited. As a rule they are found to be quite tight. Occasionally one pair of a set (but never both pairs) are found to be leaking somewhat at high tide. This is caused by rags, corks, pieces of wood, or other such matters, catching near the hinges. At such visits the gates are washed clean, the hinges greased, and the iron-work examined for traces of incipient rust.

Some of the tide-gates were made of white pine and some of spruce. A few of the latter, which have been in place for three years, already show signs of decay. These are inside gates situated above the elevation of mean tide, so that they are comparatively seldom wet. To replace them creosoted lumber will probably be used. The rubber gaskets, fastened to the gates, are in perfectly good condition after about three years' use. They were made of what was called by the manufacturer "pure rubber;" but as they cost 75 cents a pound, when crude rubber was selling at more than \$1.00 a pound, they probably merely contained a larger percentage of that material than is usual in rubber goods. They were made with special reference to resisting the effects of sewage and grease.

The penstocks, flushing-gates, and regulators are also inspected periodically. Moving parts are cleaned, slushed, and moved, so as to insure their being in good working condition. The iron, when carefully painted, does not appear to suffer from rust. About once in eight months it receives a coat of asphaltum paint. Duplicates are provided of all pins and other small parts, so that these can be taken to the yard to be warmed and recoated. The chains attached to the inlet valves, by which they are lifted, are most subject to rust. These are frequently changed and taken to the yard, where, after being cleaned and scraped, they are warmed in a furnace and coated with hot pitch.

The catch-pails under the ventilating man-hole covers are emptied as occasion demands. In some localities, and at some seasons, pails will be filled in less than a month. Others will not require attention for three months. Men drive along the sewer line with a cart, remove a man-hole cover, lift out the

pail, empty its contents into the cart, and again replace the pail and cover. A few extra pails are carried in the cart, so that if any of those in use shows signs of rust it can be replaced by another, and be taken to the yard for cleaning and recoating.

The filth-hoist at the pumping-station seems satisfactorily to answer the purpose for which it was designed. In dry weather the cages are raised three times a day, and the average daily yield from them is about 16 cubic feet. The matters intercepted are, rags, paper, corks, half lemons, lumps of fat, dead animals, pieces of wood, bottles, children's toys, pocket-books, and such-like miscellaneous articles, which by accident or design are thrown into house-pipes. Comparatively little solid fecal matter is caught, as most of it dissolves before reaching this point.

When it rains, and deposits are scoured out of the old sewers, very much more filth is caught in the cages. The amount sometimes equals three or four cubic yards in 24 hours. At such times it is necessary to raise and clean the cages every half-hour, during the night as well as in the day, in order to prevent their becoming clogged and backing up the sewage in front of them.

At first what was removed from the cages was buried in pits near the pumping-station. This not being considered a satisfactory method of disposal an attempt was made to burn the filth in the furnaces under the boilers. It was found that the filth, as taken from the cages, contained so much water that the fires were injured. Accordingly a simple press, like a cider press, was procured, by which most of the water was pressed out. The comparatively dry cakes remaining after pressing are now burned without injuriously affecting the furnace fires.

The two high-duty "Leavitt" pumping-engines and the two storm-duty "Worthington" pumping-engines have all been run more or less during the past year. Any one of them is able to pump the ordinary dry-weather flow of sewage. As a rule one of the Leavitt engines is kept running; should it rain, and additional pumping capacity be needed, the second Leavitt engine is, by preference, started; if still more capacity is needed, the Worthington engines are started. When the amount of water arriving by the sewer decreases, the Worthington engines are first stopped.

The average daily quantity of sewage pumped in dry weather is about 24,000,000 gallons, and the average number of tons of coal consumed in doing the work is about $3\frac{1}{4}$. This, with some steam used for other purposes, gives a working duty in the case of the Leavitt engine, of about 95,000,000 pounds raised 1 foot high by the consumption of 100 pounds of coal. The Worthington engines, under similar conditions, show a working duty of somewhat more than 50,000,000 foot-pounds.

The following table gives the results of the first year's pumping, beginning with February, 1884, when the works had got fairly into operation : —

MONTH. 1884.	DAILY AVERAGE GALLONS PUMPED.	DAILY AVERAGE POUNDS OF COAL.	PER CENT. OF ASHES.	GALLONS PUMPED PER POUND OF COAL.	RAINFALL.	
					Inches.	Number of Days It Rained.
February . .	25,777,360	14,028	15.8	1,836	5.74	20
March . . .	32,437,379	18,880	14.8	1,709	4.86	19
April . . .	29,949,356	15,671	16.2	1,913	4.76	17
May . . .	25,121,056	13,127	15.6	1,915	3.31	11
June . . .	26,712,298	13,265	16.5	2,015	4.01	7
July . . .	25,900,400	13,529	19.2	1,912	4.25	17
August . . .	31,674,621	14,704	16.0	2,174	5.01	14
September .	28,412,431	11,099	12.1	2,568	.31	.8
October . .	27,601,557	10,206	13.3	2,698	3.17	13
November . .	27,501,283	8,985	8.0	3,073	3.03	9
December . .	30,883,501	10,181	7.2	2,885	4.46	15
1885.						
January . .	38,498,668	11,448	7.2	3,265	5.33	9

It will be seen that the daily average, as given, is larger than the dry-weather flow, because it includes the extra quantities pumped during rains. The largest day's work thus far has been 81,280,883 gallons, but for a few hours this rate has been much exceeded. Until August, 1884, the pumping was not done economically. At that time a change was made in

the management of the station, with a considerable increase in economy. A further gain was made in November, 1884, by substituting bituminous coal for anthracite, which had previously been used. The former coal makes more steam, and costs about \$1 less a ton. The comparatively low duty shown by the table for December was due to the fact that the Worthington engines were largely used during that month, while a temporary building over the Leavitt engines was being taken down.

There are no means for determining accurately the actual amount of the city water supply in the district whose sewers are tributary to the Main Drainage System. But it is evident that even in dry weather the amount of sewage reaching the pumping-station by the main sewer is greater than the water-supply of the districts drained by it. The excess is not constant; sometimes it is estimated to be 10 per cent. of the whole, and at other times it is probably 25 per cent., or even more. This excess comes from several sources. Many dwellings and factories in sewered districts have private water supplies. Breweries, and other similar large establishments, contribute largely in this way. A single sugar refinery was found to pump and use, daily, about 1,000,000 gallons of salt water, all of which properly might have gone back into the harbor, but was, instead, turned into the sewers. In the spring, when the ground is full of water, much of it leaks into the common sewers, and is by them carried to the interceptors. Sea-water also, at high tide, finds its way along some of the old box-sewers, and leaks into them back of the tide-gates. It will probably prove to be true economy to rebuild many of the old sewers, in whole or in part.

The permanent working force employed at the pumping-station at present is as follows : —

- 1 Chief Engineer,
- 3 Assistant Engineers,
- 9 Oilers,
- 3 Firemen,
- 3 Coal-passers,
- 1 Clerk.

The men employed in the filth-hoist, included in the above, rank as oilers. The administration at this point is, of course, not as economical as it would be if there were a uniform, constant amount of work to be done.

The deposit-sewers have perfectly answered their purposes in arresting all heavy matters contained in the sewage. The cross-sectional area of these sewers is so large, and the resulting velocity of flow is so sluggish, even when four pumps are running, that all suspended matters subside before reaching the tunnel. Sand and gravel are deposited at once, as soon as they enter the sewers; lighter substances are carried a little farther; but only floating matters or those having about the same specific gravity as water, remain in suspension long enough to reach the further end of the sewers.

As elsewhere stated, the sludge, contained by the common sewers at the time connection was made between them and the intercepting sewer, passed to the pumping-station and was pumped into the deposit-sewers. The amount of this was 12,000 cubic yards, or more. The best way of removing it was long considered, and it was only in the autumn of 1884 that the appliances described in Chapter VIII. were adopted and constructed. When the six-inch pipe connecting one deposit-sewer with the sludge-tank was first opened, the deposits near where the pipe entered the sewer were drawn into the tank, which in the space of two days was filled with about 100 yards of sludge.

The floating scrapers (Plate XIX.) were not completed until the winter. They work very well, with a combined scraping and flushing action, and by their use the sand and gravel deposits can be moved from one end of the sewer to the other. The sludge-tank was filled a second time, principally with clear sand, when operations were stopped by the harbor's freezing over. The bay remained closed by ice until early in March, when the removal of the deposits was again resumed. It seems probable that this method of removal will prove as satisfactory as any which could be adopted.

As the tunnel is 142 feet below the harbor, and has been constantly full of sewage since pumping began, there has been no

opportunity for inspecting it. For the first few months of 1884, before all of the city sewers had been intercepted, a comparatively small amount of sewage was pumped, especially at night. At such times the velocity of flow through the tunnel was very slight, often less than one-half of a foot a second. Occasionally pumping would be stopped for a few hours at night, to allow the sewage to accumulate. At present the ordinary flow in the tunnel is seldom faster than 1 foot a second. As the sewage takes from two to four hours to pass through the tunnel, at these slow velocities, it was to be expected that deposits would occur there.

To ascertain the extent of such deposits, and whether they were likely to become permanent, some experiments were made. These were based upon the following laws :

That the flow through the tunnel is produced by the difference in elevation of the water at its two ends ;

That the amount of this difference is a measure of the frictional resistance which the tunnel opposes to the flow of the sewage ;

That, in proportion as the water-way of the tunnel is obstructed by deposits, the resistance, and therefore the difference in elevation of the water at its two ends, will be greater than they would be if the tunnel was clean.

The method of making the experiments was as follows :—

The quantity of water passing through the tunnel was ascertained by pump measurement, with allowance for slip. The difference in elevation at the two ends of the tunnel was determined by means of sliding gauges, with knife edges where they came in contact with the surface of the water.

The coefficient was then calculated for the formula

$$V = C \sqrt{RI} \text{ or } C = \frac{V}{\sqrt{RI}}$$

in which

V = Velocity in feet per second

R = Hydraulic mean radius = $\frac{\text{area}}{\text{wet perimeter}}$

I = Sine of inclination = $\frac{\text{head}}{\text{length}}$

C = A coefficient ascertained by experiment.

As the tunnel is circular, 7.5 feet in internal diameter, the value of R , corresponding to the full cross-sectional area, is 1.875 feet. Experiments on the flow of water in the Sudbury-River Conduit,¹ which was a brick structure like the tunnel, gave a coefficient corresponding to $R = 1.875$, of about 137. It was not anticipated that the coefficient found for the tunnel, even when it was clean, would be quite so large as that of the conduit; since the surface of the former is somewhat rougher, and some loss of head would be occasioned by changes in direction at bends and by obstructions at the east shaft.

It was also expected that the coefficient would vary somewhat with the velocity and with the dilution of the sewage. Under the most favorable circumstances, with the tunnel free from deposits, the coefficient would approximate 137, being that found by the experiments above mentioned.

The full area of the tunnel was used in determining the values of V and R . This assumed that the tunnel was clean. Should the coefficient be found to be much lower than that anticipated, it would show that the foregoing assumption was incorrect, and that the area of the tunnel was partly obstructed.

Whatever was the true value of the coefficient, its increase or decrease, as determined by successive experiments under the same conditions, would show whether the amount of deposit in the tunnel was becoming less or greater.

Arrangements are provided for flushing the tunnel by running four pumps simultaneously, salt water being admitted to the pump-wells to supply any deficiency of sewage. The volume pumped is generally at the rate of about 114,000,000 gallons per day, which gives a velocity of about four feet per second through the tunnel.

The first flushing with four pumps was done June 12, 1884. Just previous to this time, by two measurements on different days, the loss of head through the tunnel was ascertained to be about .54 of a foot, and the values of C were found to be 80 and 82. On June 13, the day after flushing, an experiment, with

¹ Transactions of the American Society of Civil Engineers, Vol. XII, No. CCLIII.

the same conditions as those previously made, gave a loss of head of .30 of a foot, and a value of $C = 110$.

This value was still too low to indicate an entirely clean tunnel, but showed that the water-way had been increased by a removal of a portion of the deposit by the flushing. This was known to be a fact, since the sludge scoured out by the flushing had been observed in the reservoir. Inspection showed that the deposit carried into the reservoir was of a very light nature, containing soft mud, horse-manure, water-logged match ends, bits of lemon-peel, paper, and similar substances.

Beginning in June, 1884, flushing with four pumps has been done regularly about once a fortnight. At four different times measurements to determine the value of C have been made during the flushing. At such times the velocity of flow is high, and from 75 to 80 per cent. of the volume pumped is clean salt water, affording conditions favorable for obtaining a high coefficient. The values of C , derived from these several experiments, were as follows : —

June 12, 1884.	$C = 129$.
Oct. 20, 1884.	$C = 120.7$.
Jan. 15, 1885.	$C = 146.3$.
Feb. 16, 1885.	$C = 146.6$.

The last two experiments were made on days following periods when the quantity of sewage pumped had been unusually large, on account of rain and melting snow, which may account for the largeness of the coefficients. There may, also, have been some unusual slip in the valves. There can be little doubt, however, that at this time the water-way of the tunnel was not appreciably obstructed.

Since these were experiments on the flow through a large pipe they may have some general interest for engineers, and their details are given in the following table : —

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	REMARKS.
Number of Experiment.	Date of Experiment.	Length of Tunnel.	Diameter of Tunnel.	Loss of Head in Tunnel.	Loss of Head per Foot (l). "	Hydraulic mean Radius (R).	Volume in cubic Feet per Second.	Mean Velocity (V).	Value of C in Formula $V = C \sqrt{\frac{H}{R}}$	
1.	June 6, 1884.	7166 feet.	7.5 feet.	0.520 feet.	.00007256	1.875 feet.	41.06	0.929	79.95	Sewage.
2.	" 9, "	"	"	0.566 "	.00007894	"	44.08	0.998	82.00	"
3.	" 12, "	"	"	3.648 "	.0005091	"	176.24	3.988	129.05	20 to 25 per cent. sewage; 75 to 80 per cent. salt water.
4.	" 13, "	"	"	0.297 "	.0000414	"	42.64	0.965	109.66	Sewage.
5.	Oct. 20, "	"	"	4.165 "	.0005812	"	173.56	3.929	120.67	20 to 25 per cent. sewage; 75 to 80 per cent. salt water.
6.	Jan. 15, 1885.	"	"	2.700 "	.0003768	"	172.16	3.897	146.31	" "
7.	Feb. 16, "	"	"	2.950 "	.0004103	"	179.43	4.062	146.64	" "

NOTE. — In the first four experiments the quantities in column 5 are the total differences in elevation of the water surface at the two ends of the tunnel, less a correction for loss of head at entrance. In the remaining experiments the head, a short distance below the entrance to the tunnel, was taken, and no correction was required. The tunnel has one quarter-turn of 9.75 feet radius and one angle of 23½ degrees. These increase the resistance somewhat. On the other hand, the farther end of the tunnel enlarges gradually as a diverging tube, which facilitates the flow.

The wooden flume between Squantum and Moon Island has been watched carefully during the past year. It was at first tight, but the effect of the summer's sun lying on one side of it tended to make the planks shrink and warp somewhat, so that leakage occurred in some places. These were stopped by tightening the bolts and wedges, and by fastening the corner bottom planks to the sides with lag screws. To guard against the sun the flume was given a second coat of paint. Putting a cheap roof over it would, doubtless, prolong the duration of its effective service:

When the sewage in the reservoir is low, the flume runs about half-full. As the basins fill, the depth of flow increases until finally it runs entirely full, acting as a pipe. The ordinary velocity of flow is about three feet a second, or less as the depth increases. Twice a day, when the reservoir is flushed, as described later on, the current through the lower end of the flume attains the remarkable velocity of about seven feet a second. This velocity is sufficient to move stones and brickbats.

Nevertheless the flume is not clean. From its bottom up to the ordinary flow line the sides are covered with a slimy deposit from one-eighth to one-quarter of an inch in thickness. Above the middle and on the top there is also some slime, but not so much as below. The condition of this sewer is commended to the attention of those sanitarians who are accustomed to represent flushing as a certain remedy for the accumulation of slime in pipes.

Some experiments were made to determine the value of C in the formula $V = C \sqrt{RI}$ as applied to the flume. In one trial, the flume flowing about half-full with sewage, the value of R was 1.45 feet, the velocity was 2.94 feet a second, and the value of C was found to be 116.9. In a second trial, under similar conditions, the following values were obtained: $R = 1.41$; $V = 2.87$; $C = 116.6$. In a third trial, when four pumps were running and the flume was flowing full, 75 to 80 per cent. of the water pumped being clean salt water, the values of R , V , and C respectively, were 1.5, 4.80, and 134.8. It will be noticed that the value of R was about the same in the last trial as in the first two, but that the value of C was very much greater. It is thought that

this may be due to the fact that the first trials were made with clear sewage, whereas, in the case of the last trial, the water was comparatively clean. It seems reasonable to suppose that some head would be expended in maintaining in suspension the solid particles contained by the sewage. The subject is worthy of further investigation, because it concerns the applicability to the flow of sewage of hydraulic formulæ derived from experiments on the flow of clean water.

The reservoir has a capacity of 25,000,000 gallons. As sewage is stored in it for about ten hours at a time, between the end of one period of discharge and the beginning of another, the basins, as a rule, have been filled only about half-full during the past year. The process of discharging is begun about one hour after the beginning of ebb tide. By this time the surface of the sea is as low as the bottom of the reservoir, and a good harbor current is setting outwards past the outlet. Water is admitted to the turbine, and by the power transmitted from it the upper gates in the outfall sewer are first closed. The sewage then arriving is thus stored in the sewer, and its surface rises several feet. Meantime the lower gates in the discharge sewer are opened, and the sewage in the reservoir flows through them to the outlet. Under ordinary circumstances the basins are emptied in about 30 minutes.

There is left in the basins a thin deposit of semi-fluid mud, generally about one-quarter of an inch thick, but in greater quantity after storms. To remove this, flushing is first resorted to. During the past year four brick partition-walls were built across the gallery between the sewers and the reservoir. One of these was built opposite the middle of each basin. As soon as a basin is empty an upper gate is opened on one side of the dividing wall just mentioned, and the lower gates on the other side of it. The sewage, which has by this time accumulated to a considerable depth in the outfall sewer, passes through the openings into one side of the basin, and flows with moderate force up the gutters to the back retaining-wall. As the gutters fill the sewage overflows across the ridges and down the gutters on the other side of the basin. Much of the sludge is in this way washed off into the gutters and carried into the discharge

sewers. The flushing is done alternately from one and the other side of the basin.

If a basin cannot thus be entirely cleaned, men descend into it with broad wooden scrapers, convex on one side, to fit the gutters, and flat on the other. With these the mud is scraped into the gutters and pushed down into the gallery, whence it is washed out into the sea at the next time of discharge. Such cleansing operations occupy about one-half hour for each basin, and are not especially disagreeable for the men.¹

When the sides of a basin need cleaning the pump in the engine-house is started, and one or more lines of hose are coupled to the hydrants on the 4-inch pipe fastened to the floor in the middle of each basin. The pump will give two strong fire streams with sufficient force to wash off any crust which has hardened on the walls. The streams can also be used in connection with scraping and washing the floors of the basins.

The first sewage which discharges at the outlet contains a considerable amount of sludge which has settled in the gallery and discharge sewers, and gives to the effluent a dark, muddy appearance. After a few minutes the color is somewhat lost, and the effluent looks like moderately dirty water.

Its effect in discoloring the salt water, and its course as it joins the current out of the harbor, can be plainly noticed. Being fresh water it rises to the surface, and when a half-mile from the outlet seems to lie on top of the salt water in a stratum but a few inches thick. The greasy nature of the sewage tends to quiet the ripples commonly seen on the surface of the harbor, so that the area affected by the discharge is plainly determined. From experiments with floats it is known that the sewage travels nearly five miles, following the Western Way and Black-Rock Channel out to the vicinity of the Brewster Islands. By the time it has travelled a mile from the outlet most of the color is lost, and by the time it has gone two miles (before passing Rainsford Island) not the slightest trace of it can be distinguished.

¹ Since this was written slight changes have been made in the method of flushing the floors and gutters, which render the operation so effective that it is no longer necessary to send men into the basins to clean them.

When the works went into operation, and for the first nine months thereafter, there were no gates near the outlet at the end of the discharge sewers. As a consequence the last portion of sewage from the reservoir, filling the discharge sewers, flowed out into the harbor slowly as the tide fell. This was the dirtiest part of the sewage, because it contained scourings from the basins. By referring to the plan (Plate V.) it will be seen that a cove was formed between the island and the pier containing the discharge sewers. In this cove a foot or more of sludge accumulated. A thin layer of sludge also formed on the beach between the outlet and the extreme point of the island. This last-named deposit was only found between the levels of mid-tide and low water.

In winter no smell comes from these deposits, and in summer none is noticed except during low tide. On three occasions last summer, when the wind was from the east, the smell was so strong as to be noticed at Squantum, a mile away.

In hopes of preventing, or at least lessening, the formation of such deposits, a set of gates have been placed in the chamber at the outlet. By these the sewage filling the discharge sewers is held back until the beginning of the succeeding discharge, when it is forced out into a good current. These gates have not been in place long enough to show how much they will accomplish; but, should objectionable deposits still continue to form on the island, it is thought that an effectual remedy can be provided. This will consist in building a solid bulkhead wall near the line of low water, from the outlet to the extreme easterly point of the island. Such a structure could be built for \$30,000.

No trace of the sludge has been found on the shores in any other part of the harbor. Very little smell emanates from the reservoir in cool weather; not enough to be perceptible at a contractor's boarding-house, about 200 feet distant. In summer the smell is more noticeable; but not nearly so much so as is that arising from the deposits of sludge on the beach.

As a whole, the Main Drainage System works well, and no radical defect has been detected in any portion of it. It is not

claimed that, by itself, it furnishes a perfect system of sewerage for the city. Many defective house-drains and common sewers still exist, and must in time be replaced; but the new system provides an outlet for the rest, without which other reforms would be comparatively useless.

By building the Main Drainage Works, Boston has taken the first, most essential step in the direction of efficient sewerage.

APPENDIX.

APPENDIX A.

RECORD OF TESTS OF CEMENT MADE FOR BOSTON MAIN DRAINAGE WORKS.

1878-1884.¹

THE Main Drainage Works chiefly consist of brick, stone, and concrete masonry. About 180,000 barrels of cement were required to build this masonry; and to insure its stability and durability it was necessary that the cement should be of good quality. From the start, therefore, means for determining the qualities of all cements used or offered for use were provided. A room was set apart for these operations and an inspector appointed to conduct them.

The tests were devised, principally, in order to determine three points, namely:—

1. The relative strength and value of any cement as compared with the average strength and value of the best quality of similar kinds of cements.
2. The absolute and comparative strength and value of mortars of different kinds made from the same cement.
3. The effect produced upon the strength of any cement mortar by different conditions and methods of treatment.

This knowledge was chiefly sought by observations of the tensile strength of the cements and mortars tested. Reasons for adopting the tensile test were, that it required comparatively light strains to produce rupture; that, as it was universally used, it afforded results which could be compared with those of other observers; and, finally, because the tensile stress is precisely that by which the mortar of masonry, in most cases of failure, actually is broken.

All the particles of any cement are of appreciable size, and its strength as a mortar depends on the extent to which the particles adhere, at their points of contact, to each other or to some inert substance. This adherence may be overcome and the mortar broken, either by pulling the particles apart by tension, or by pushing them past each

¹ A paper presented to the American Society of Civil Engineers.

other by compression. The effect upon the adhering quality of the particles is not very different in the two operations; but in the latter the friction of the particles against each other must also be overcome, which requires the application of very much more force. Transverse tests are only tensile tests differently applied, and shearing produces a stress intermediate to tension and compression. When masonry is strained, one part of it is in tension, another in compression, and, as mortar yields more readily to tensile stress, failure generally occurs by rupture of the joints in tension.

Briquettes for testing, with a breaking section of one square inch, were first used; but it was thought that these, from their small size, were liable to be strained and injured by handling in taking them from the moulds and transferring them to the water. A larger pattern, with a breaking section one and one-half inches square, or two and one-quarter square inches, was finally adopted. Comparative tests with briquettes of one inch and two and one-quarter inches section respectively indicated that there was little, if any, difference in their strength per square inch.

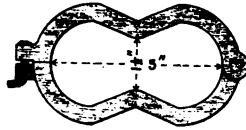
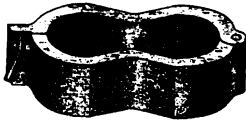
The shape of the briquette adopted is shown by Fig. 2, Plate XXVIII. Fig. 1 of the same plate shows the brass moulds in which the mortar was packed to form the briquettes. These moulds proved very satisfactory. They were strong, and easily clamped and opened. The clamp consisted of a piece of brass wire riveted loose in the projecting lug of one branch of the mould, and binding by friction when turned against the wedge-shaped lug on the other branch. If a fastening worked loose a single tap of the hammer would tighten it. All breaking loads were reduced to pounds per square inch of breaking section by multiplying by four and dividing by nine.

Before testing a cement its color was first observed. The absolute color of a natural cement indicates little, since it varies so much in this particular. But, for any given kind, variations in shade may indicate differences in the character of the rock or in the degree of burning. With Rosendale cements a light color generally indicated an inferior or underburned rock. An undue proportion of underburned material was indicated in the case of Portland cement by a yellowish shade, and a marked difference between the color of the hard-burned, unground particles retained by a fine sieve and the finer cement which passed through the sieve.

The weight per cubic foot was also sometimes ascertained. As this would vary with the density of packing, a standard for comparison was adopted, which was the density with which the cement would pack itself by an average free fall of three feet. The apparatus used

BRASS MOULD.

Fig. 1.



BRIQUETTE.

PAT OF CEMENT TESTED FOR CHECK CRACKS.

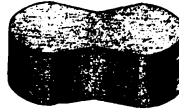


Fig. 2.

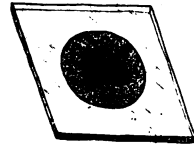


Fig. 4.

TUBE AND BOX FOR WEIGHING CEMENT.

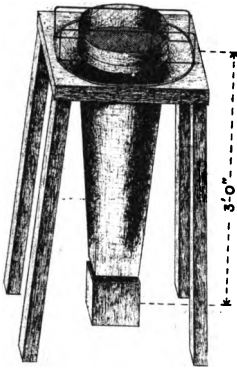


Fig. 3.

PAN FOR KEEPING BRIQUETTES.

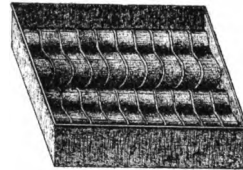
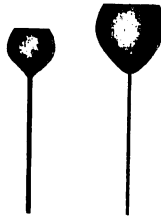


Fig. 6.



LIGHT & HEAVY WIRES.

Fig. 5.



Fig. 7.



Fig. 8.

FOR TAKING SAMPLES FROM BARRELS.

BARREL OF CEMENT
60 PER CENT FINE

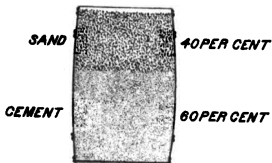


Fig. 9.

BARREL OF CEMENT
SUPER CENT FINE

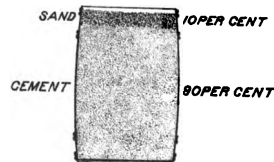


Fig. 10.

is shown by Fig. 3, Plate XXVIII. The cement was placed in a coarse sieve on the top of a galvanized iron tube, and, the sieve being shaken, the cement sifted through the tube into the box below. This box held exactly one-tenth of a cubic foot when struck level with its top.

The weights per cubic foot as determined by this method varied considerably with different kinds and brands of cement, and somewhat with different samples of the same brand. The averages were as follows :—

TABLE No. 1.

Rosendale	49 to 56 pounds.
Lime of Teil	50 “
Roman	54 “
A fine-ground French Portland	60 “
English and German Portlands	77.5 to 87 “
An American Portland	95 “

The following table shows the effect of fine grinding upon the weight of cement. It gives the weight per cubic foot of the same German Portland cement, containing different percentages of coarse particles, as determined by sifting through the No. 120 sieve :—

TABLE No. 2.

0 per cent. retained by No. 120 sieve — W't per cubic foot . . 75 pounds.						
10	“	“	“	“	“	. . 79 “
20	“	“	“	“	“	. . 82 “
30	“	“	“	“	“	. . 86 “
40	“	“	“	“	“	. . 90 “

It was soon discovered that there was no direct ratio between weight and strength. As a general rule, subject to exceptions, heavy cement, if thoroughly burned and fine-ground, was preferred to light cement. Fine-ground cements were lighter than coarse-ground and underburned rock lighter than well-burned. While color and weight by themselves indicated little, yet, considered together and also in connection with fineness, they enabled the inspector to guess at the character of a cement, and suggested reasons for high or low breaking. A cement which was light in color and weight, and also coarse-ground, would be viewed with suspicion.

The test of fineness, which followed, was considered of great importance, as showing the quantity of actual cement contained in a barrel, and its consequent value. Small scales were used, made

for this purpose by Fairbanks & Co. One-quarter of a pound of the sample was weighed out and passed through the sieve. The coarse particles retained by the sieve were returned to the scales, whose balance-beam carried a movable weight, and was graduated in percentages of one-quarter pound. The percentage of coarse particles retained by the sieve could thus be read directly from the beam.

Standard sieves, varying from No. 50 to No. 120, were used. The number of meshes to the lineal inch in any sieve is commonly supposed to correspond with its trade number. As sold, however, they vary somewhat, and the number of wires is generally less, by about ten per cent., than the number of the sieve. A No. 50 sieve commonly has about 45 meshes to the inch, and a No. 120 about 100, or a few more. In important contracts, where a certain degree of fineness was called for, it was customary carefully to compare two sieves and retain one, which was specified as the standard, while the other was delivered to the manufacturer for his guidance.

In accordance with common practice the No. 50 sieve was first used. It was soon discovered, however, that so coarse a sieve did not always give a correct indication of the fineness of the cement. This was especially true of Portland cements. Some brands, chiefly German, were evidently bolted by the manufacturers with special reference to tests by this sieve, in which they would leave no residuum. Yet the bulk of such cements, while containing no very coarse particles, might prove quite coarse when tested by the No. 120 sieve.

It is obvious that pieces of burned cement slag one-fourth of an inch in diameter would have no cementing quality, and the same is true of particles one one-hundredth of an inch in diameter. At precisely what smaller size the particles begin to act as cement it was impossible to determine. Those retained by a No. 120 sieve, in which the open meshes are approximately one two-hundredth of an inch square, were found to have some slight coherence, even after washing to remove the finer floury cement which was sticking to them. It was also found that the No. 120 sieve was about as fine a one as it was practicable to use, on account of the time required to sift the cement through it. It was, therefore, adopted as a standard.

Assuming (what was only approximately verified by experiments on tensile strength) that only what passed through this sieve had real value as cement, and that the rest was not very different from good, sharp sand, the difference in the quantity of actual cement obtained in purchasing barrels 60 and 90 per cent. fine, respectively, is shown

by Figs. 9 and 10, Plate XXVIII. This has an important bearing on the proportion of sand to be added in practical use; for when mortar is mixed for use in the proportion of one barrel of cement to two of sand, if there be nine parts of cement and one of sand in the barrel of cement itself, the actual proportion in the mortar will be .9 to 2.1 or 1 to 2.33. If there be only six parts of cement and four of sand in the barrel of cement the resulting proportion in the mixture will be .6 to 2.4 or 1 to 4.

Fine cement can be produced by the manufacturers in three ways: by supplying the mill-stones with comparatively soft, underburnt rock, which is easily reduced to powder; by running the stones more slowly, so that the rock remains longer between them; or by bolting through a sieve and returning the unground particles to the stones. The first process produces an inferior quality of cement, while the second and third add to the cost of manufacturing.

The extra cost, as estimated by a firm of English manufacturers, of reducing a Portland cement from an average of 70 per cent. fine, tested by No. 120 sieve, to 90 per cent. fine, was 18 cents per barrel. The price at which 5,000 barrels of their ordinary make, 70 per cent. fine, were offered, delivered on our work, was \$2.82 per barrel. The same cement, ground 88 per cent. fine, was delivered for \$3 a barrel. On the foregoing assumption of the value of fine and coarse particles, the city, by accepting the first offer, would have obtained in bulk 3,500 barrels of actual cement and 1,500 barrels of sand for \$14,100. By accepting the second offer it obtained in bulk 4,400 barrels of cement and 600 of sand for \$15,000; that is, the 900 additional barrels of cement cost \$1 a barrel. Experiments illustrating the value of fine grinding, and further comments, will be given later.

Tests were made both of neat cement and of cement mixed with sand in different proportions. The latter were preferred, because they showed the strength and value of the mortars used in actual work. It was found also that the strength of briquettes made of neat cements did not always indicate the capacity of these cements to bind sand, or the strength of the mortars made with them. This is illustrated by experiment No. 10, on page 127.

The greater the proportion of sand in the mortar tested the more accurately was the actual cementing quality of the cement indicated. As, however, very weak mixtures took a long time to harden, and were liable to injury from handling, one part cement to three parts sand was adopted as the usual mixture for testing Portland cements, and one to one and one-half or two for American cements. Occasionally when testing large quantities of some well-known brand, the object

being to see that a uniform strength was maintained, it was found sufficient, and simpler, to omit the sand and make the briquettes of cement only.

In making mortars for testing, rather coarse, clean, sea-beach sand was used.

The subsequent strength of the briquettes depended largely upon the amount of water with which they were gauged. The highest results were obtained by using just enough water thoroughly to dampen the cement, giving the mass the consistency of fresh loam, which became pasty by working with a trowel. For ordinary testing, sufficient water was added to make a plastic mortar, somewhat stiffer than is commonly used by masons. Different cements varied in the amounts of water needed to produce this result. As a rule American cements needed more water than Portland, fine ground more than coarse, and quick-setting more than more slow-setting cements. Experiment No. 9, page 127, shows the comparative strength of mortars gauged with different percentages (in weight of the cement) of water. The standard adopted was 25 per cent. for Portland cement and 33 per cent. for Rosendale; but these amounts were increased or diminished by the operator to suit the circumstances, his aim being to obtain mortars of unvarying consistency.

The way in which the test briquettes were made was as follows: the moulds, having been slightly greased inside to prevent the mortar sticking to them, were placed on a polished marble slab. This support for them was used because it was easily cleaned and the mortar did not stick to it. Experiment No. 6, page 124, shows that the use of porous or of non-porous beds to support the moulds does not materially affect the strength of the mortars. The requisite amounts of cement and sand for one briquette were weighed out and incorporated dry in a mixing-pan. The proper amount of water was also weighed out and added, and the mass worked briskly with a small trowel until of uniform consistency. A brass mould was half filled with the mortar, which was rammed into place by the operator with a small wooden rammer, in order to displace any bubbles of air which might be confined in it. The mould was then filled to its top with the remaining mortar, which was in turn rammed down. Finally the mortar was struck even with the top of the mould and given a smooth surface by the trowel.

The amount of mortar packed in the mould, and the consequent density of the briquette, would vary with any variation in the degree of force exerted by the operator in ramming. This variation was reduced to a minimum by always mixing a fixed amount of mortar,

which was barely more than sufficient to fill one mould. Irregularities in ramming would thus be detected by variations in the amount of surplus mortar, and could be checked. An attempt was made to do away wholly with this element of uncertainty by pressing the mortar into the moulds with certain fixed pressures. Apparatus was devised and used for this purpose, but was finally abandoned on account of the length of time required for its use.

The initial energy of the cement — that is, the length of time after mixing before it “set” — was determined by noting the length of time before it would bear “the light wire” of $\frac{1}{16}$ inch in diameter loaded with $\frac{1}{4}$ -pound weight, and also “the heavy wire” $\frac{1}{8}$ inch in diameter loaded with 1-pound weight. At the former time the cement was said to have begun to set, and at the latter it was entirely set. Different kinds and brands of cement varied greatly in the time after mixing when they would bear the wires. Some brands of English Roman cement would set in two minutes, and some of Portland required over 12 hours. Cold retarded the setting, and fresh-ground cements set quicker than older ones. No direct relation was established between initial energy and subsequent strength. By judicious mixing of quick and slow setting cements a mixture could be obtained which would set within any desired period.

As soon as the briquettes were hard enough to handle without injury, which with different cements and mixtures varied from five minutes to twelve or more hours, they were removed from the moulds and placed in numbered pans filled with water. Before removal each briquette had marked upon it, with steel stamps, the name of the cement, date of mixing, and a number by which it could be further identified. The inscription might read thus: —

“Alsen 1-3. May 17, 1880. 47.”

Records were also kept in books and on blanks provided for the purpose. The briquettes were kept in the pans, covered with water, until they were broken. Their age when broken varied from 24 hours to five years.

In testing a well-known American cement, of generally uniform quality, if it were an object to save time, the comparative excellence of the samples could be sufficiently determined by a 24 hours' test of briquettes made of neat cement. Under similar conditions neat Portland cement could be tested in seven days. To test mortar of either kind of cement took a week, or, better, a month; especially if there was a liberal proportion of sand.

The probable value of an untried brand of cement could hardly

be ascertained with certainty in less than a month, and not always then. To illustrate the occasional need of long-time tests a case may be cited.

A new brand of cement, made by some patent process, was offered for use on the work. When tested it set up well, and at the end of a week the neat cement had a tensile strength of 184 pounds per square inch. In a month this had increased to 267 pounds, indicating a strength equal to that of a low-grade Portland cement. At this time there was nothing in the appearance of the briquettes to indicate any weakness. Yet after about six months they fell to pieces, and had entirely lost their cohesive quality.

The briquettes were broken by a machine made for the Department by Fairbanks & Co. It worked with levers, acting on a spring balance, which was tested from time to time, and found to maintain its accuracy.

During the progress of the work the following brands of cement were submitted for approval, and were tested with more or less thoroughness:—

Old Newark, Newark and Rosendale, Norton, Hoffman, Old Rosendale, New York and Rosendale, Lawrenceville, Rosendale, Arrow, Keator, Howe's Cave, Rock Lock, Buffalo, Cumberland, Round Top, Selenitic, Vorwholer, Star, Dyckerhoff, Alsen, Hemmor, Bonnar, Onward, Burham, J. B. White, Knight, Bevan & Sturge, Brooks, Shoobridge & Co., Leavitt, Grand Float, Diamond, Spanish, Red Cross, La Farge, Lime of Teil, Saylor, Coolidge, Walkill, Cobb, Abbott.

The following is a record of the more instructive tests, made for experimental purposes. Nearly all of them were made with special reference to the work then in hand, to elucidate some practical questions affecting the purchase, testing, or use of the cements needed for building purposes. The names of the brands of cement tested in the several experiments are generally omitted. This is in order to avoid any unwarranted use of the results as recorded.

The figures given in the tables always represent average breaking loads in pounds per square inch of breaking section.

EXPERIMENT No. 1.

Of natural American cements the Rosendale brands (so called) are the only ones which find a sale in the Boston market, and they were chiefly used on the work. Imported Portland cements were also largely used. It was important, therefore, to ascertain the actual and

comparative strengths of these cements. The following table gives results compiled from about 25,000 breakings, of 20 different brands, and fairly represents the average strength of ordinary good cements of the two kinds. Some caution, however, is necessary in using the table as a standard with which to compare other cements. Quick-setting cements might be stronger in a day or week, and show less increase in strength with time. Fine-ground cements would probably give lower results tested neat, and higher ones with liberal proportions of sand.

TABLE No. 3.

ROSENDALE CEMENT.

NEAT CEMENT.					CEMENT, 1; SAND, 1.				CEMENT, 1; SAND, 1.5.				CEMENT, 1; SAND, 2.				CEMENT, 1; SAND, 3.				CEMENT, 1; SAND, 5.			
1 Day.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.
71	92	145	232	290	56	116	190	256	41	95	155	230	24	60	125	180	14	35	80	121	5	16	46	80

PORTLAND CEMENT.

NEAT CEMENT.					CEMENT, 1; SAND, 1.				CEMENT, 1; SAND, 1.5.				CEMENT, 1; SAND, 2.				CEMENT, 1; SAND, 3.				CEMENT, 1; SAND, 5.			
1 Day.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.	1 Wk.	1 Mo.	6 Mos.	12 Mos.
102	303	412	468	494	160	225	347	387	..	...	...	..	128	163	279	323	95	140	198	257	55	88	136	155

The table is instructive in several ways. It shows that Portland cement acquires its strength more quickly than Rosendale; that both cements (but especially Rosendale) harden more and more slowly as the proportion of sand mixed with them is increased; that, whereas neat cements and rich mortars attain nearly their ultimate strength in six months or less, weak mortars continue to harden for a year or more. The table shows the advantage of waiting as long as possible before loading masonry structures, and the possibility of saving cost by using less cement when it can have ample time to harden. It also shows that Portland cement is especially useful when heavy strains must be withstood within a week.

EXPERIMENT No. 2.

These series of tests are like the preceding ones, except that a single brand of cement was used in making each. The average breaking loads per square inch were obtained from a less number of briquettes (about 500 in all), mortars with larger proportions of sand were included in the series, and the tests were extended for two years.

TABLE No. 4.

PORTLAND CEMENT MORTAR.

Age when Broken.	Neat Cement.	Cement, 1; Sand, 2.	Cement, 1; Sand, 4.	Cement, 1; Sand, 6.	Cement, 1; Sand, 8.	Cement, 1; Sand, 10.	Cement, 1; Sand, 12.
One week .	295	166	89	50	33	23	17
One month .	341	243	132	88	67	50	41
Six months .	374	343	213	149	98	76	51
Two years .	472	389	226	159	98	49	31

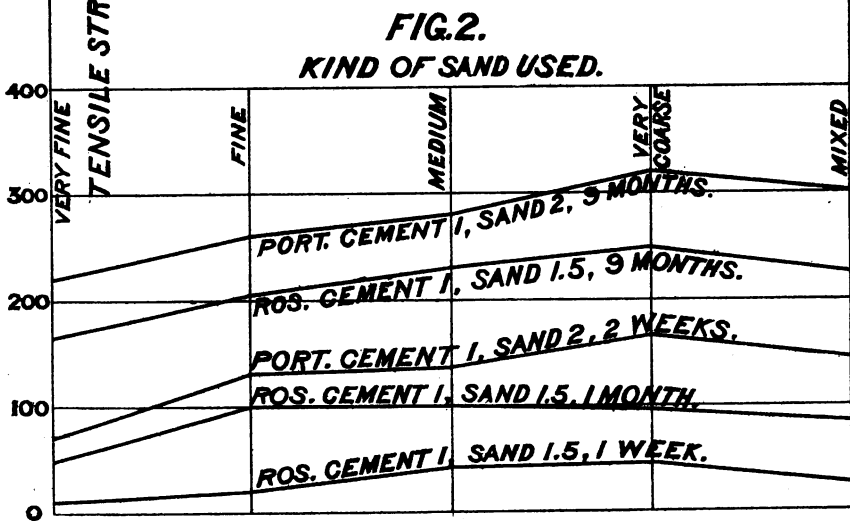
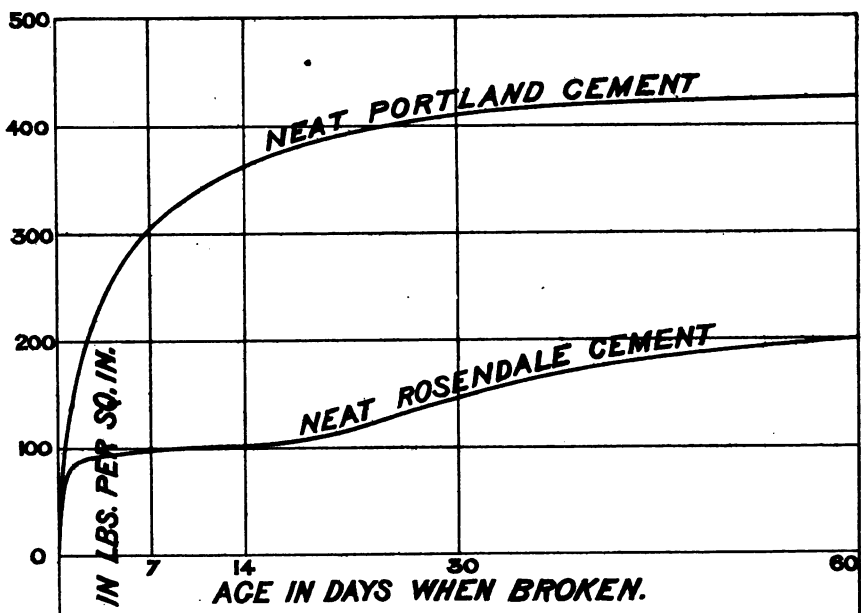
ROSENDALE CEMENT MORTAR.

Age when Broken.	Neat Cement.	Cement, 1; Sand, 2.	Cement, 1; Sand, 4.	Cement, 1; Sand, 6.	Cement, 1; Sand, 8.	Cement, 1; Sand, 10.	Cement, 1; Sand, 12.
One week		24	7	5			
One month		83	33	17	8	5	
Six months		172	93	62	50	33	21
Two years		211	90	56	33	22	20

The tables show that considerable strength is acquired in time, even when a very large proportion of sand is used; also, that most mortars increase very little, if any, in tensile strength after six months or a year. They become harder with time, but also become more brittle and probably less tough. Specimens of mortar two years old, or more, break very irregularly.

EXPERIMENT No. 3.

The rate at which Rosendale and Portland cements, respectively, increase in strength during the first two months after mixing is very different, and has some bearing on their use, and more on the interpretation of tests of them made within that period. The curves (Fig.



1, Plate XXIX), which indicate this rate of increase, were compiled from tests with neat cement. It is probable that tests with mortar would give somewhat similar results. By comparing the two curves it appears that after 24 hours Rosendale cement has about three-fourths of the strength of Portland. While the latter increases greatly in hardness during the next few days, the energy of the former becomes dormant, so that at the end of a week the Portland cement is more than three times as strong as the Rosendale. During the second week the Portland cement increases more slowly, and the Rosendale continues nearly quiescent. At about this period, and for the next six weeks, the Rosendale cement gains strength, not only relatively, but actually faster than the Portland, so that when two months old the former has one-half the strength of the latter. After two months the relative rate of increase and the comparative strength of the two cements remain nearly unchanged. A series of tests with a Buffalo cement, and one with a Cumberland cement, gave results similar to those with Rosendale cement.

EXPERIMENT No. 4.

For making tests it is not always convenient to obtain sand of uniform size, and still less so to obtain such sand in sufficient quantities for use in work. The curves, Fig. 2, Plate XXIX, record some tests made to determine the effect of fineness and of uniformity of size in sand upon the strength of mortars made with it.

The curves show that for comparative tests it is advisable to have sifted sand of nearly uniform size; that mortars made with coarse sand are the strongest, and that the finer the sand the less the strength. It also appears that mixed sand, *i.e.*, unsifted sand containing a mixture of particles from coarse to fine, makes nearly as strong a mortar as coarse or medium coarse sand. For use in work, therefore, it is well to avoid fine sands; but it is not necessary to have sand of uniform size, or to sift out a moderate proportion of fine particles.

EXPERIMENT No. 5.

As some experimenters on cement use a test briquette with a breaking section of 1 square inch, and others one with a section of $2\frac{1}{4}$ square inches, the following experiment was made to determine the difference, if any, in the strength acquired by the same mortars moulded into briquettes of these different sizes. Two series of tests were made, in the same way, with the same mortars. In one series the briquettes had a breaking section of 1 square inch, and in the

other the section was $2\frac{1}{2}$ square inches. The results are given in the following table, in which the figures represent breaking loads in pounds per square inch, and are averages from five breakings : —

TABLE No. 5.

	ROSENDALE CEMENT.						PORTLAND CEMENT.						
	Neat Cement.				Cement, 1; Sand, 1.5.		Neat Cement.			Cement, 1; Sand, 1.5.			
	1 Day.	1 Week.	1 Month.	6 Months.	1 Week.	1 Month.	6 Months.	1 Week.	1 Month.	6 Months.	1 Week.	1 Month.	6 Months.
1-inch Section . . .	49	73	156	286	27	53	236	309	460	657	60	96	175
2½-inch Section . . .	49	78	173	258	27	62	311	347	391	578	67	108	230

As is usual, the breaking loads are somewhat irregular, the inch section excelling at some points, and the larger section at others. The experiment, however, seems to indicate that neither size will, as a rule, give higher results than the other.

EXPERIMENT No. 6.

Some experimenters have thought it important to place the moulds in which the mortar is packed for testing upon a porous bed, such as blotting-paper or plaster. Others use a non-porous bed of glass, slate, or marble. The following series of tests were made to discover the effect of these different modes of treatment. The figures in the tables represent breaking loads, in pounds per square inch, and are averages of about ten breakings.

TABLE No. 6.

ROSENDALE CEMENT.

Mixture.	Kind of Bed.	One Week.	One Month.	Six Months.	One Year.
Neat . . {	Marble . .	95	151	288	325
	Plaster . .	106	178	303	316
Cement, 1, Sand, 1.5.	Marble . .	44	107	210	251
	Plaster . .	62	120	219	265

A CUMBERLAND CEMENT.

Mixture.	Kind of Bed.	One Day.	One Week.	One Month.	Six Months.	One Year.
Neat . . .	Marble . . .	128	133	142	231	241
	Plaster . . .	147	165	176	244	257
Cement, 1 . .	Marble . . .	. . .	107	161	275	339
Sand, 1.5 . .	Plaster . . .	. . .	128	166	299	345
Cement, 1 . .	Marble . . .	. . .	85	134	201	292
Sand, 2 . . .	Plaster . . .	. . .	111	148	241	294
Cement, 1 . .	Marble . . .	. . .	40	94	162	163
Sand, 4 . . .	Plaster . . .	. . .	46	91	164	170

GERMAN PORTLAND CEMENT.

Mixture.	Kind of Bed.	One Week.	One Month.	Six Months.	One Year.
Cement, 1,	Marble . .	259	367	390	
Sand, 1 .	Plaster . .	213	376	411	
Cement, 1,	Marble . .	176	256	346	345
Sand, 2 .	Plaster . .	196	258	326	357
Cement, 1,	Marble . .	141	225	250	313
Sand, 3 .	Plaster . .	147	220	258	312
Cement, 1,	Marble . .	103	157	240	274
Sand, 4 .	Plaster . .	120	150	233	264
Cement, 1,	Marble . .	82	108	182	213
Sand, 5 .	Plaster . .	103	140	193	197

Making allowance for a few irregularities, it appears, from the foregoing tables, that the use of a porous bed gives slightly higher results for the first one or two months, but that the difference disappears or becomes insignificant with age.

EXPERIMENT No. 7.

It is a well-recognized fact that in experimenting with cements, even when great care is exercised, individual specimens break very irregularly, and that results even approximately conforming to theory can only be obtained from averages from a large number of breakings. The personal equation of the operator, and the degree of force with which he presses the mortar into the moulds, is one factor in producing irregular results. To do away with this a machine for packing the moulds was devised and used for a time. By this the mortar was pressed into the moulds by a metallic plunger, acting with definite pressures, varying from 50 to 400 pounds.

The machine-made briquettes broke with somewhat greater uniformity than hand-made ones. So much more time was required to make briquettes with this machine that it was found to be impracticable to employ it for general use.

EXPERIMENT No. 8.

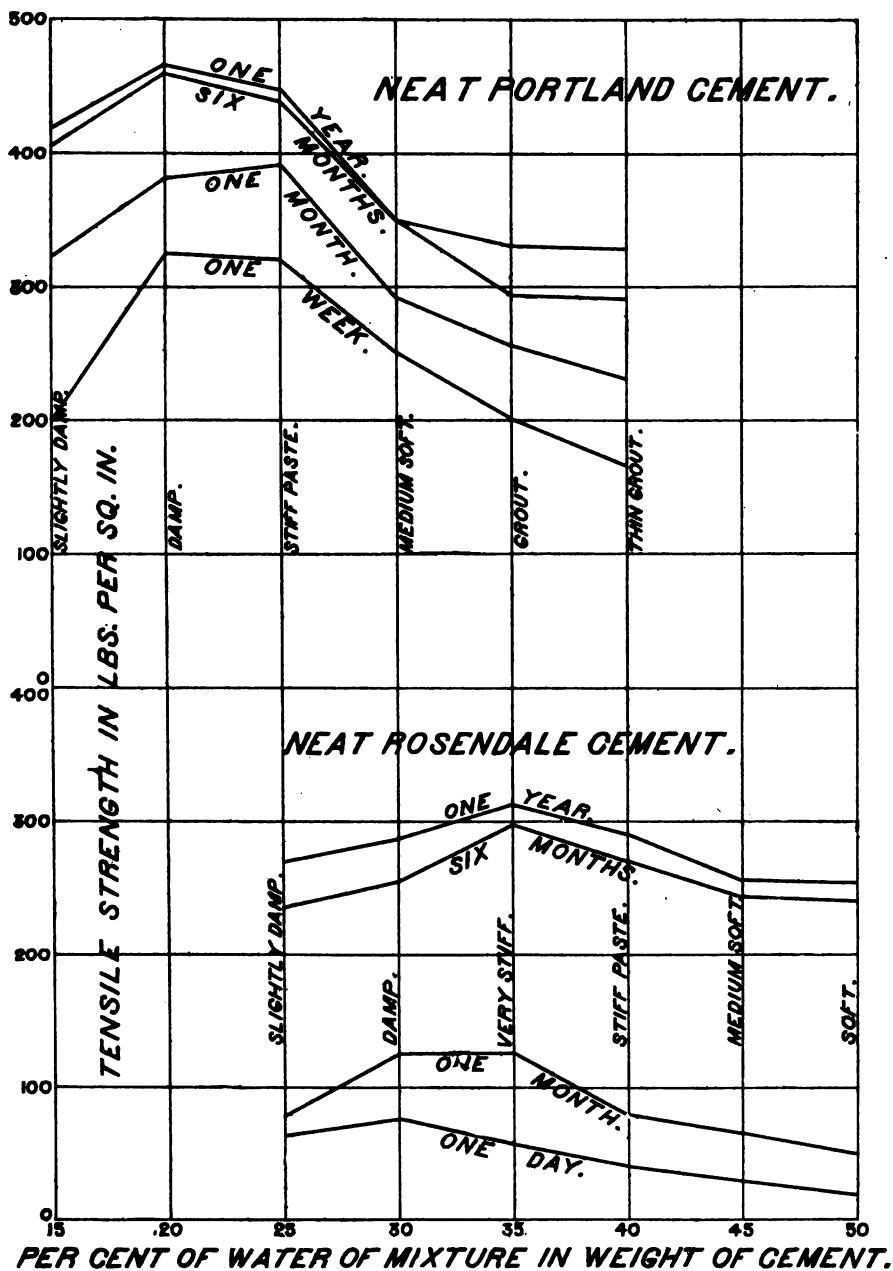
By the sea it is frequently convenient to mix mortar with salt water. Brine is also used in winter as a precaution against frost. This experiment was made to obtain the comparative effect of mixing with, and immersing in, fresh and sea water respectively. The tests were made upon a Rosendale mortar, mixed one part cement to one part sand, and an English Portland mortar, one part cement to two parts sand. The figures are averages of about ten breakings, and give the tensile strength in pound per square inch with the different methods of treatment and at different ages.

Except for some irregularity in the breakings for one year (which may have been due to the manipulation) the table indicates that salt, either in the water used for mixing or that of immersion, has no important effect upon the strength of cement. Salt water retards the first set of cement somewhat.

TABLE No. 7.

ROSENDALE CEMENT MORTAR, 1 TO 1.					PORTLAND CEMENT MORTAR, 1 TO 2.			
Fresh Water.	Fresh.	Salt.	Salt.	Mixed with	Fresh.	Fresh.	Salt.	Salt.
Fresh Water.	Salt.	Fresh.	Salt.	Immersed in	Fresh.	Salt.	Fresh.	Salt.
40	48	50	61	One week. .	151	122	152	149
126	135	114	126	One month.	213	191	203	200
247	250	243	224	Six months.	314	245	277	264
310	263	224	217	One year. .	342	231	346	295

PLATE XXX.



EXPERIMENT No. 9.

This was an experiment to determine the relation existing between the stiffness of cement mortar when first mixed and its subsequent strength. The stiffness depends on the proportion of water used in mixing, and varies somewhat with different cements. Natural American cements take up more water than Portland cements and fine-ground more than coarse cements. Many series of tests bearing on this point were made. The results obtained from two of the more complete series are shown by the curves on Plate XXX. The cements used in these tests were a rather coarse English Portland and a fair Rosendale. Each of the points in the curves represents an average from about ten briquettes. The cements were tested neat, and the amounts of water used were different percentages, by weight, of the amounts of cement. The resulting stiffness of mortar is indicated on the curves. This varied from the consistency of fresh loam to a fluid grout. The time of setting is greatly retarded by the addition of water.

The curves show that from 20 to 25 per cent. of water gives the best results with Portland cement, and from 30 to 35 per cent. with Rosendale; that the differences in strength due to the amount of water are considerable at first, but diminish greatly with age; that the soft mortars, even when semi-fluid, like grout, attain considerable strength in time.

EXPERIMENT No. 10.

From the first it was observed that fine-ground cements were less strong when tested neat, and stronger when mixed with sand, than were coarse cements. A few examples of this are given below. In the first table a coarse English Portland cement is compared with a fine-ground French Portland. The per cent. of each retained by the fine No. 120 sieve is given, and the tensile strength, in pounds, per square inch at the end of seven days.

TABLE No. 8.

Kind of Cement.	Per Cent. retained by No. 120 Sieve.	Parts of Sand to 1 part of Cement.				
		0	2	3	4	5
English Portland	37	319	125	89	59	43
French Portland	13	318	205	130	114	86

Such examples could be multiplied. German Portland cements were commonly finer ground than English, and, as a rule, were no stronger, or less strong, tested neat, but were much stronger with liberal proportions of sand. In the following table two lots of the same brand of English Portland cement are compared. The coarse cement was the ordinary make of the manufacturers; the fine cement differed in no particular from the other except that it was ground more slowly and finer to meet the requirements of a special agreement. The age of the samples when broken was 28 days.

TABLE No. 9.

Kind of Cement.	Per Cent. retained by No. 120 Sieve.	Parts of Sand to 1 part of Cement.		
		0	3	5
Ordinary Cement	35	403	105	68
Fine-ground Cement	12	304	180	96

Different brands of Rosendale cement varied considerably in their fineness. Those of the best reputation would leave from 4 to 10 per cent. residuum in the No. 50 sieve; other brands would leave in the same sieve from 10 to 23 per cent. In the following table is compared the average tensile strength obtained from experiments with three of the finer-ground brands, and also with three other brands of good reputation, but more coarsely ground. The age of the specimens was one week.

TABLE No. 10.

Kind of Cement.	Per Cent. retained by No. 50 Sieve.	Parts of Sand to 1 part of Cement.		
		0	1.5	2
Fine Rosendale	6	92	41	25
Coarse Rosendale	17	98	29	16

The foregoing experiments show that it is impossible, by tests on the tensile strength of neat cements alone, to judge of their value

in making mortars, for practical use; also, that fine-ground cements make stronger mortars than do coarser ones.

A number of series of tests were made of cements which had been sifted through sieves of different degrees of fineness, and had thereby had different percentages of coarse particles removed from them. The results from these experiments were quite uniform, and showed that, in proportion as its coarse particles were removed, a cement became more efficient for making mortars with sand. The following table gives the results obtained from one such series of tests made with an English Portland cement. In the experiment comparison is made between the strength of mortars made with the ordinary cement, unsifted as it came from the barrel, and those made with the same cement after having been sifted through Nos. 50, 70, 100, and 120 sieves, which, respectively, eliminated more and more of the coarse particles. The per cent. of particles which would still be retained by the fine No. 100 sieve, after sifting through the coarser sieves, is given in the second column of the table. There is included in the table an extra coarse cement, which was made so by adding to unsifted cement a certain amount of the coarse particles taken from the sifted cements. The tensile strength is given in pounds per square inch.

TABLE No. 11.

KIND OF CEMENT USED IN MAKING MORTARS.	PER CENT. OF PARTI- CLES REMAINED BY No. 120 Sieve.	ONE WEEK.				ONE MONTH.				SIX MONTHS.				ONE YEAR.			
		Parts of Sand to 1 part of Cement.															
		2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5
Cement with coarse particles added . .	55	72	39	32	19	117	80	67	40	210	135	122	84	200	128	112	92
Ordinary Cement, un- sifted	83	129	92	58	43	197	143	109	88	311	236	183	136	288	247	168	165
Cement which passed No. 50 Sieve . . .	28	159	97	67	47	210	158	125	102	324	246	190	146	328	249	214	170
Cement which passed No. 70 Sieve . . .	18	163	117	82	65	239	168	151	112	338	256	225	173	342	295	230	193
Cement which passed No. 100 Sieve. . .	8	177	123	84	73	255	185	156	122	257	288	239	182	382	307	257	215
Cement which passed No. 120 Sieve. . .	0	198	154	95	86	271	200	161	132	379	320	238	196	386	316	262	218

In a similar series of tests with Rosendale cement mortars, the increase in strength obtained by substituting fine for coarse particles in the cement was much less marked. The coarse particles were softer than those from Portland cement, and had, in themselves, some power of cohesion. As previous tests had shown that fine-ground Rosendale cements were stronger, with sand, than coarse-ground, it was assumed that the superiority was due, not so much to the absence of palpably coarse particles, as to the fact that the bulk of the cement was more floury, and thus better adapted to coating and binding the particles of sand. Probably natural American cement is as much improved as is Portland cement by fine grinding, but in the case of the former there would not be the same relative advantage in bolting out the coarse particles after grinding.

The following series of tests may be of interest, on account of the age of the specimens. The mortars were made with an English Portland cement, both unsifted as taken from the cask, and also after it had been sifted through the No. 120 sieve, by which process about 35 per cent. of coarse particles was eliminated.

TABLE No. 12.

KIND OF CEMENT.	NEAT CEMENT.		CEMENT, 1; SAND, 2.		CEMENT, 1; SAND, 5.	
	2 Years.	4 Years.	2 Years.	4 Years.	2 Years.	4 Years.
Ordinary Cement, unsifted	608	387	339	493	182	202
Cement which passed No. 120 Sieve . .	374	211	478	580	250	284

This table, also, shows that fine cements do not give as high results tested neat as do cements containing coarse particles, even coarse particles of sand. It also shows (what is often noticed) that neat cements become brittle with age, and are apt to fly into pieces under comparatively light loads.

The series of tests which follows was made for the purpose of ascertaining what value, if any, for cementing purposes, was possessed by the hard, coarse particles of Portland cement. Mortars were made with an ordinary English Portland cement, and compared with similar mortars made with the same cement, after sifting through the No. 120 sieve, which retained 33 per cent. of coarse particles.

TABLE No. 13.

KIND OF CEMENT.	ONE WEEK.			ONE MONTH.			SIX MONTHS.			ONE YEAR.		
	Parts of Sand to one part of Cement.											
	0	2	3	0	2	3	0	2	3	0	2	3
Ordinary Cement, unsifted .	353	139	86	279	201	142	438	323	253	444	343	271
Cement which passed No. 120 Sieve :	311	187	132	243	275	201	268	367	310	306	434	333

As usual, the coarse cement was stronger neat, and weaker with sand. Assuming that the 33 per cent. of coarse particles retained by the sieve had *no* value as cement, acting merely as so much sand, and assuming also that all which passed through the sieve was good cement, it follows that the ordinary unsifted cement with two parts of sand, made a mortar in which the proportion of real cement to sand was .67 to 2.33, or about 1 to 3.5. Hence, the mortar made with fine cement and three parts of sand should be as strong, or a little stronger, than that made with the coarse cement and two parts of sand. It will be seen that the results in the table sustain the assumption very well.

If, then, the coarse particles are assumed to act merely as so much sand, it will not lessen the efficiency of the cement to remove its coarse particles, and to substitute actual sand in their place. This was done in making the following series of tests. One set of briquettes was made with ordinary cement, and another set with the same cement, from which 33 per cent. of coarse particles had been removed and replaced with fine sand.

TABLE No. 14.

KIND OF CEMENT.	ONE WEEK.		ONE MONTH.		SIX MONTHS.		ONE YEAR.	
	Parts of Sand to one part of Cement.							
	2	3	2	3	2	3	2	3
Ordinary Cement, unsifted,	139	86	201	142	324	253	343	271
Cement with 33 per cent. coarse particles removed and fine sand substituted.	101	67	160	100	253	206	305	240

These briquettes refused to break in accordance with the theory, and the assumed hypothesis was not verified. It is evident that, for making mortar, the coarse particles of Portland cement are superior to ordinary sand, but much inferior to fine cement. In the mortars made with the cement, in which the coarse particles had been replaced with fine sand, the real proportions of cement to sand were 1 to 3.5 and 1 to 5. It will be noticed that the tensile strength was not reduced in like proportion.

EXPERIMENT No. 11.

While building masonry laid in American cement mortar it is sometimes desirable to increase the strength of the mortar temporarily or in places. Rich Portland cement mortars are expensive, and those with large proportions of sand are too porous for many purposes. The desired strength can be gained by using, instead of the simple American cement, the same cement mixed with a percentage of strong Portland cement.

The following series of tests was designed to ascertain the comparative strength of mortars made with a Rosendale cement, an English Portland cement, and also a mixture composed of equal parts of each:—

TABLE No. 15.

Kind of Mortar.	1 Week.	1 Month.	6 Months.	1 Year.
Rosendale Cement, 1; Sand 2 . .	26	60	125	180
Rosendale Cement, 0.5, } Sand, 2 .	79	138	263	273
Portland Cement, 0.5, }				
Portland Cement, 1; Sand, 2 . . .	126	163	279	323

In the foregoing tests the mortar made with mixed cement had an unexpected strength, approximating to that of mortar made with pure Portland cement. In the following series of tests of mortars made with lime of Teil, a fine-ground French Portland cement, and the lime and cement mixed, the strength of the mortar made with the mixture is almost exactly a mean between those of the other two mortars, as also the cost of the mixed cement is a mean between the costs of the other two.

TABLE No. 16.

Kind of Mortar.	1 Week.	1 Month.	6 Months.	1 Year.
Lime of Teil, 1; Sand, 2	40	65	150	195
Lime of Teil, 0.5, } Sand, 2 . .	100	135	255	290
Portland Cement, 0.5, }				
Portland Cement, 1; Sand, 2 . . .	170	265	350	365

The best Portland cements sometimes do not set within an hour, which precludes their use for wet work. In such cases quick-setting cement should be added to them. Roman cements can be procured which will set in from one to five minutes. Mixtures of Roman and Portland cements were often used on the Main Drainage Works. Such mortars would set about as quickly as if made with Roman cement alone, and would acquire great subsequent strength, due to the Portland cement contained in them. This was proved by many experimental tests.

It is probable that mixtures of any good cements can be used without risk; but before adopting any novel combination it would be wise to test it experimentally.

EXPERIMENT No. 12.

Engineers are accustomed to require that only clean sand and water shall be used in making mortar. Occasionally these requirements cause delay and extra expense. This experiment was designed to ascertain how much injury would be caused by the use of sand containing moderate proportions of loam. In mixing the mortar for these briquettes, sand containing 10 per cent. of loam was used in the place of clean sand. Each figure in the table is an average (in pounds per square inch) of ten breakings.

TABLE No. 17.

ROSENDALE CEMENT, 1; SAND, 1.5; LOAM, .15.

One Week.	One Month.	Six Months.	One Year.
21	46	200	221

The tests do not give very decisive results. For one week and one

month the breaking loads are not much more than one-half what would have been expected with clean sand. For six months and a year they are fully equal to ordinary mortar.

EXPERIMENT No. 13.

This experiment was similar to the foregoing one, except that clay, instead of loam, was added to the mortar. Clay, when dissolved or pulverized, consists of an almost impalpable powder, with particles fine enough to fill the interstitial spaces among the coarser particles of cement. By adding clay to cement mortar a much more dense, plastic, and water-tight paste is produced, which was occasionally found convenient for plastering surfaces or stopping leaky joints. Each figure in the Portland cement series of tests is an average from about fifteen briquettes; those in the Rosendale cement series are averages from ten briquettes.

TABLE No. 18.

ROSENDALE CEMENT.

	Cement, 2; Clay, 1.	Cement, 1; Clay, 1.	Cement, 1; Sand, 1.5.	Cement, 1; Sand, 1.5; Clay, 0.15.	Cement, 1; Sand, 1.5; Clay, 0.3;	Cement, 1; Sand, 1.5; Clay, 0.45.
1 week . . .	32	23	50	52	34	33
1 month . . .	108	52	123	116	101	100
6 months . .	303	206	217	248	247	236
1 year . . .	208	209	262	290	265	261

PORTLAND CEMENT.

	Cement, 2; Clay, 1.	Cement, 1; Clay, 1.	Cement, 1; Sand, 2.	Cement, 1; Sand, 2; Clay, 0.2.	Cement, 1; Sand, 2; Clay, 0.4.	Cement, 1; Sand, 2; Clay, 0.6.
1 week . . .	185	192	150	197	185	145
1 month . . .	263	271	186	253	245	203
6 months . .	348	322	320	361	368	317
1 year . . .	303	301	340	367	401	384

The tests seem to show that the presence of clay in moderate amounts does not weaken cement mortars.

It was feared that the presence of clay in mortars exposed to the weather might tend to make them absorb moisture and become disintegrated. To ascertain whether this would be so, sets of briquettes were made, one set of Portland cement and sand only, the other containing also different amounts of clay. They were allowed to harden in water for a week, and were then exposed on the roof of the office building for two and one-half years, when they were broken. All of the briquettes appeared to be in perfectly good condition, with sharp, hard edges. Their average tensile strengths in pounds per square inch are shown in the following table:—

TABLE No. 19.

Portland Cement 1; Sand 2	402
“ “ “ Clay 0.5	262
“ “ “ “ 1.0	256
“ “ “ “ 1.5	182
“ “ “ “ 2.0	178

The mortars with clay show a very fair degree of strength, and the tests confirm the belief that the presence of clay works little, if any, harm. Tests of mortars made with lime and clay also gave favorable results. Such mortars would stand up in water. The subject is worthy of further investigation.

EXPERIMENT No. 14.

Occasionally, for stopping leaks through joints in the sewers, it was found convenient to use cement mixed with melted tallow. The tallow congealed at once and held the water while the joint was being calked. Briquettes made of melted tallow mixed with Portland cement and sand, equal parts, acquired in 1 week, a tensile strength of about 40 pounds to the inch. After a month, six months, and a year, they were little, if any, stronger. It was thought that possibly the ammonia in the sewage might gradually saponify and dissolve out the grease, leaving the mortar to harden by itself. Briquettes of cement and tallow were kept in water, to which a little ammonia was added from time to time. After a year or two the briquettes had swelled to about double their former size, but the cement had acquired no strength.

EXPERIMENT No. 15.

Having occasion to build with concrete a large monolithic structure, in which a flat wall would be subjected to transverse stress, it was considered necessary to make experiments, to find the comparative

resistance to such stress of concrete made with different cements and with different proportions of sand and stone.

The cements used in the tests were an English Portland and a Rosendale, both good of their respective kinds. Medium coarse pit sand was used, and screened pebbles about an inch or less in diameter. The beams were ten inches square and six feet or less long. They were made in plank moulds resting on the bottom of a gravel-pit about four feet deep. After the concrete had hardened sufficiently, the moulds were removed, and the undisturbed beams buried in the pit and left for six months exposed to the weather. They were then dug out, and broken with the results given in the table. The total breaking loads are given, including one-half of the weights of the beams, which averaged about 150 pounds per cubic foot. The constant, c , is obtained for the formula : —

$$w = \frac{d^3 \times b}{l} \times c, \text{ in which } \left\{ \begin{array}{l} w = \text{centre breaking load in pounds.} \\ d = \text{depth of beam in inches.} \\ b = \text{breadth of beam in inches.} \\ l = \text{distance between supports in feet.} \\ c = \text{a constant.} \end{array} \right.$$

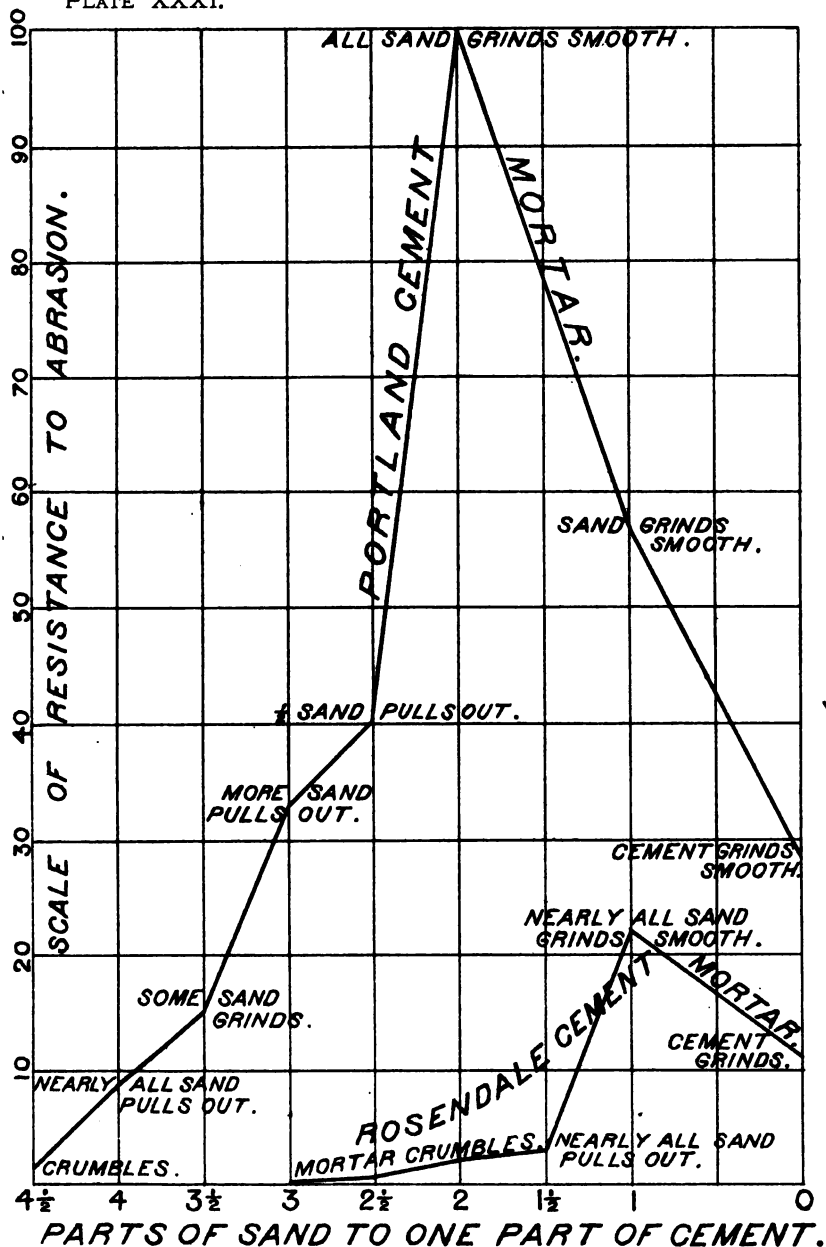
Since c has an average value, and there were generally more beams of one length than the other, the value of c as given does not exactly correspond with either load in the table.

TABLE NO. 20.

PROPORTION OF MATERIALS.			AVERAGE CENTRE BREAKING WEIGHT IN POUNDS.		Average Modulus of Rupture in Pounds.	Average Value of c in Pounds.
Cement.	Sand.	Stone.	Dist. between Supports, 2' 4½".	Dist. between Supports, 5'.		
Rosendale, 1 .	2	5	1,782	690	67	3.7
“ 1 .	3	7	Beams broke in handling.			
Portland, 1 . .	3	7	3,926	1,995	176	9.8
“ 1 . .	4	9	3,648		146	8.1
“ 1 . .	6	11	2,822	1,190	112	6.2

The table shows that concrete has a rather low modulus, especially when made of Rosendale cement. When transverse stress is to be opposed it is very important to give ample time for the concrete to harden.

PLATE XXXI.



EXPERIMENT No. 16.

Many of the main drainage sewers were either built or lined with concrete, which was always smoothly plastered with a coat of mortar. It was important that this surface coat should be especially adapted to resist abrasion. This experiment was made to ascertain the best mixture for the purpose. Different mortars were formed into blocks $1\frac{1}{2}$ inches square, and, after hardening under water for 8 months, were ground down upon a grindstone. The blocks were pressed upon the stone with a fixed pressure of about 20 pounds. A counter was attached to the machine, and the number of revolutions required to grind off 0.1 inch of each block was noted. The cements used in the test blocks were a rather coarse English Portland and a fair Rosendale.

The curves (Plate XXXI.) show the results obtained. In making these curves the resistance to abrasion opposed by the Portland cement mortar in the proportion of one part cement and two parts sand is assumed to be 100, and the resistance of other mortars is compared with it. The effect of the grinding upon the test blocks is noted on the curves, and explains the somewhat striking results.

It appears that cements oppose the greatest resistance to abrasion when combined with the largest amount of sand which they can just bind so firmly that it will grind off and not be pulled out. A little less or a little more of sand may greatly lessen the resistance. For any given cement the proper amount of sand would, probably, have to be ascertained by experiment.

EXPERIMENT No. 17.

It is a prevalent belief among masons that cement, even when it contains no free lime, and does not check, expands considerably after setting. It is stated that brick fronts laid with cement mortar (especially of Portland cement) have been known to bulge, and even rise, owing to expansion in the mortar. Experiments were made to ascertain what truth there was in this belief. Several dozens of glass lamp-chimneys were filled with mortars made of various brands of American and Portland cements, both neat and with different admixtures of sand. The chimneys were immersed in water, and, without exception, began to crack within three days. New cracks appeared during the following ten days, after which time hardly a square inch of glass remained which did not show signs of fracture. This showed that the cement certainly expanded, though very slowly, and that the expansion continued for about two weeks. None of the cracks opened

appreciably, however, so that the *amount* of expansion, which was evidently slight, could not thus be even approximately determined.

A number of 10-inch cubes were then made of similar mortars, with small copper tacks inserted in the centres of all the sides. Some of these cubes were kept in the air, and others immersed in water, and the sizes of all of them were measured frequently by callipers during six months. The increase in size did not in any case exceed .01 inch, and may have been less. This indicated that, while cement mortars do expand, the increase in bulk in any dimension does not exceed .001 part of that dimension, and is too slight to be of consequence. In the case of the walls before referred to, supposing them to have been 80 feet high, with five $\frac{1}{4}$ -inch joints to each foot, the total height of mortar would have been 100 inches, and the extreme expansion of the whole could only have been .1 inch. It is probable that the apparent rise was merely a difference in elevation caused by settlements of partition or side walls laid with weaker and compressible mortar.

EXPERIMENT No. 18.

It having been reported that cement mortars in contact with wood had sometimes been found to be disintegrated, as if they might have been affected by the wood acids, this experiment was made to see if any such effect could be detected. About a dozen boxes were made, each formed of five different kinds of wood, viz., oak, hard-pine, white-pine, spruce, and ash. The boxes were filled with different cement mortars, and were some of them submerged in fresh and others in salt water. Briquettes were also made of cements mixed with different kinds of sawdust. At the end of a year no effect upon the cements could anywhere be detected.

EXPERIMENT No. 19.

Engineers are accustomed to insist on cement mortars being used before they have begun to set, and on their being undisturbed after that process has begun. With cements that set quickly workmen are tempted to retemper the mortar after it has begun to stiffen. Some experiments were made on mortars which were undisturbed after first setting, and others which were retempered from time to time. Unfortunately all of the conditions of these tests were not accurately recorded, and the results are not considered trustworthy. The following series of tests, which represents an extreme case not met with in actual practice, may be of interest.

A mortar made of one part of Portland cement and two parts of sand was allowed to harden for a week. It was then pulverized, re-tempered, and made into briquettes. These subsequently acquired the following tensile strength in pounds per square inch : —

1 week	7
1 month	13
6 months	49
2 years	93

Under the circumstances it is somewhat surprising that the mortar developed as much strength as it did. Good tests to elucidate this subject are much needed.

EXPERIMENT No. 20.

A brand of "Selenitic" cement was offered for use on the work, and was said to possess great merits. It was made by treating an ordinary American cement by a patented process. It was tested by comparing it with an untreated sample of the same cement of which it was made. The following are the results of the tests : —

TABLE No. 2.

Mixture.	Kind of Cement.	1 Day.	1 Week.	1 Month.	6 Months.	1 Year.
Neat. . .	Untreated .	124	135	140	164	186
Cement . .	Selenitic .	149	168	171	282	273
Cement, 1 .	Untreated .		121	176	296	316
Sand, 1.5 .	Selenitic .		120	158	276	356
Cement, 1 .	Untreated .		92	154	259	305
Sand, 2 . .	Selenitic .		103	133	226	276
Cement, 1 .	Untreated .		38	87	153	168
Sand, 4 . .	Selenitic .		49	97	167	164

The breakings are somewhat irregular, but seem to show that this cement was made somewhat stronger by the selenitic process of treatment when tested neat, but was little, if at all, improved for use as a mortar ; not enough, certainly, to compensate for the higher cost.

APPENDIX B.

LIST OF OFFICERS CONNECTED WITH BOSTON MAIN DRAINAGE WORKS.

Commission of 1875.

E. S. CHESBROUGH, C.E.

MOSES LANE, C.E.

C. F. FOLSOM, M.D.

Engineers.

City Engineers.

JOSEPH P. DAVIS	1876-1880.
HENRY M. WIGHTMAN	1880-1885.

Principal Assistants to City Engineer.

HENRY M. WIGHTMAN	1876-1880.
ALPHONSE FTELEY	1880-1884.

Principal Assistant in Charge of Main Drainage Works.

ELIOT C. CLARKE	1876-1885.
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Assistant Engineers.

WILLIAM JACKSON	1876-1885.
FREDERIC P. STEARNS	1880-1885.
CLEMENS HERSCHEL	1878-1880.
GEORGE S. RICE	1877-1880.
GEORGE H. CRAFTS	1877-1881.
SETH PERKINS	1877-1885.
CHARLES S. GOWEN	1880-1881.
E. R. HOWE	1877-1880.
F. A. MAY	1876-1880.
F. W. RING	1876-1877.
R. TAPPAN	1876-1877.

Principal Superintendents of Construction.

Sewer Construction.

H. A. CARSON.

Pumping-Station.

S. H. TARBELL.

Joint Special Committee on Improved Sewerage.

1876.

Aldermen.

ALVAH A. BURRAGE, Chairman.
 SOLOMON B. STEBBINS.
 THOMAS J. WHIDDEN.

Councilmen.

EUGENE H. SAMPSON.
 J. HOMER PIERCE.
 WARREN K. BLODGETT.
 MARCELLUS DAY.
 ALBERT H. TAYLOR.

1877.

Aldermen.

CHOATE BURNHAM, Chairman.
 CHARLES W. WILDER.
 LUCIUS SLADE.

Councilmen.

EUGENE H. SAMPSON.
 J. HOMER PIERCE.
 WARREN K. BLODGETT.
 MARTIN L. HAM.
 GEORGE L. THORNDIKE.

1878.

Aldermen.

THOMAS J. WHIDDEN, Chairman.
 SOLOMON B. STEBBINS.
 LUCIUS SLADE.

Councilmen.

EUGENE H. SAMPSON.
 GEORGE L. THORNDIKE.
 J. HOMER PIERCE.
 FREDERICK B. DAY.
 JAMES B. RICHARDSON.

1879.

Aldermen.

LUCIUS SLADE, Chairman.
 SOLOMON B. STEBBINS.
 DANIEL D. KELLY.

Councilmen.

ISAAC ROSNOSKY.
 THOMAS J. DENNEY.
 JOHN P. BRAWLEY.
 DANIEL J. SWEENEY.
 OSCAR B. MOWRY.

. 1880.

Aldermen.

LUCIUS SLADE, Chairman.
ASA H. CATON.
GEORGE L. THORNDIKE.

Councilmen.

DANIEL J. SWEENEY.
CHARLES H. PLIMPTON.
HOWARD CLAPP.
MALCOLM S. GREENOUGH.
BENJAMIN BRINTNALL.

1881.

Aldermen.

LUCIUS SLADE, Chairman.
WILLIAM WOOLLEY.
CHARLES H. HERSEY.

Councilmen.

HOWARD CLAPP.
THOMAS J. DENNEY.
MALCOLM S. GREENOUGH.
FRANK E. FARWELL.
JOHN E. BOWKER.

1882.

Aldermen.

LUCIUS SLADE, Chairman.
WILLIAM WOOLLEY.
CHARLES H. HERSEY.

Councilmen.

MALCOLM S. GREENOUGH.
THOMAS J. DENNEY.
FRANK E. FARWELL.
PRENTISS CUMMINGS.
NATHAN G. SMITH.

1883.

Aldermen.

LUCIUS SLADE, Chairman.
WILLIAM WOOLLEY.
THOMAS H. DEVLIN.

Councilmen.

MALCOLM S. GREENOUGH.
THOMAS J. DENNEY.
FRANK E. FARWELL.
JOHN B. FITZPATRICK.
PATRICK J. DONOVAN.

1884.

Aldermen.

LUCIUS SLADE, Chairman.
CHARLES H. HERSEY.
MALCOLM S. GREENOUGH.

Councilmen.

THOMAS J. DENNEY.
PATRICK J. DONOVAN.
ISAAC ROSNOSKY.
J. EDWARD LAPPEN.
JAMES B. GRAHAM.

1885..

Aldermen.

PATRICK J. DONOVAN, Chairman.
GEORGE CURTIS.
WILLIAM J. WELCH.

Councilmen.

EDWARD P. FISK.
J. EDWARD LAPPEN.
JOHN GALLAGHER.
WILLIAM H. MURPHY.
BENJAMIN B. JENKS.

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